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Growth Rate of Stony Corals of Broward County, Florida: Effects from Past Beach Renourishment Projects

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EFFECTS FROM PAST BEACH RENOURISHMENT PROJECTS

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ABSTRACT

The skeletal growth of hermatypic (reef-building) corals is a sensitive indicator of environmental conditions and perturbations. In particular, excessive sedimentation and turbidity act to depress coral growth because energy expenditure is required to remove sediment and because turbidity reduces light energy necessary for coral health and nutrition.

Normalized annual growth (linear skeletal extension) rates of Broward County, Florida reef-building corals were examined over 16 years (1985-1970). Star corals (Montastrea annularis) and brain corals (Diploria labyrinthiformis) were collected from each of four reef sites at two depths (9m and 18m). Collection areas were located in the vicinity of possible adverse sedimentation/turbidity effects from one or more of six past beach renourishment projects.

Coral growth differences among sites at particular years and among years within sites were statistically evaluated. Years tested included those of and subsequent to each of six past beach renourishment projects. The results are suggestive that, in general, Broward County beach renourishment projects have had minor or no influence on currently living off-shore corals.

However, following the Hollywood-Hallandale renourishment project of 1979, D. labyrinthiformis from the Hollywood 18m site exhibited significantly lower normalized growth compared to other sites. This may not represent effects from the renourishment project. At the Hollywood site M. annularis from both 9m and 18m and D. labyrinthiformis from 9m did not exhibit significantly lowered growth in comparison to other sites.

Site averages of absolute coral growth indicated that southern 9m specimens had higher rates of growth than northern counterparts for M. annularis. In the southern collection sites, 9m growth of both species tended to be greater than 18m growth.

Correlation analysis indicated that the time pattern of coral growth is similar among sites, species, and depths. Comparison of time series of coral growth data to recorded environmental variables (temperature and salinity) revealed a positive relation with salinity (water density) variations.

1. INTRODUCTION

1.1) PURPOSE OF THIS STUDY

A growth survey of stony corals from reefs of Broward County, Florida was initiated to evaluate the ecological effects of past beach renourishment projects. Annual skeletal growth rates over at least 1985-1970 were measured for two coral species: Montastrea annularis (star coral) and Diploria labyrinthiformis (brain coral). Specimens were selected from two depths (approximately 9m and 18m) at each of four reef areas (near Hollywood, Ft. Lauderdale, Pompano Beach, and Deerfield Beach). Sites were chosen for assessment because of their proximity to sand borrow areas used for past beach renourishment projects conducted during one or more of the years: 1970, 1971, 1973, 1976, 1977, 1979, and 1983.

1.2) BACKGROUND INFORMATION

1.2.1) Coral Environmental Relations

Reef-building corals are coelenterate animals. Residing within their living animal tissue are symbiotic photosynthetic dinoflagellate algae, called zooxanthellae. In return for relative protection, these plant cells provide the coral animal with nutrients and assistance in removal of metabolic wastes. Coral animal tissue secretes a skeleton of calcium carbonate for structural support and living space. The coral-algal relationship promotes skeleton formation and relatively rapid growth rate. Fast growth is important because over time hermatypic (reef-building) corals produce massive skeletons which, together with many others, can serve as the structural framework of a coral reef.

Hermatypic corals occur primarily within warm and clear sub-tropical waters and require specialized conditions for their growth, health, and survival. Because of their narrow range of ecological parameters, they are sensitive to a variety of environmental perturbations. Good reviews of the subject are provided by Wells (1957), Yonge (1963), Stoddart (1969), Buddemeier and Kinzie (1976), and Pastorok and Bilyard (1985).

The algal association requires that reef-building corals receive and utilize light energy of greater or lesser amounts depending upon species. Consequently, an important requirement for coral health is that turbidity in the ambient water be relatively low. Particulate material in the water column increases light attenuation and may, after certain levels are reached, adversely affect corals through decreased light availability.

Physical sedimentation onto corals may also occur in the presence of turbidity effects. Most coral species have a limited ability to shed sediment which has fallen onto their surfaces. High sedimentation rates, however, may produce stress whereby the coral has to divert energy from growth and reproduction to sediment removal. Although there is a gradient of species specific responses, heavy sedimentation can destroy all or part of the coral tissue through smothering effects (e.g., Rogers, 1983; Hubbard and Pocock, 1972; Bak and Elgershuizen, 1976).

Most coral species prefer salinities of normal open ocean values. Corals and reefs are rare or absent near river mouths or estuaries, although some species may show a wide range of salinity tolerance.

The temperature regime for hermatypic corals must be tropical to subtropical. Extremely high temperatures may be lethal and coral reefs are rare, depopulated, or absent where the mean annual temperature falls below approximately 18 degrees centigrade. Many species have both an optimum temperature and salinity for best growth and survival. "Deviation of salinity and/or light from optimal values may narrow the range of tolerable temperatures and interfere with vital temperature related physiological mechanisms in reef corals." (Coles and Jokiel, 1978). Finally, corals require sufficient quantities of additional nutrients in the form of zooplankton, bacteria, or dissolved organics. The relative importance of various nutrient sources has not been determined with accuracy.

1.2.2) Coral Growth

The calcium carbonate coral skeleton is not a block of solid limestone material. Rather, it is composed of a more or less dense network of interconnecting architectural elements designed for structural integrity. A unique feature of the coral skeleton provides a tool for evaluation of past events or processes which may have impacted the coral organism. The skeletons of many coral species contain alternating cycles of high and low density calcium carbonate architecture. These growth increments or bands are visible through X-radiography of medial slabs of the coral skeleton. A complete cycle of high and low density skeleton material has been shown to be annual in a number of studies (e.g., Knutson et al., 1972; Dodge et al., 1974; Dodge and

Thompson, 1974; Macintyre and Smith, 1974; Noshkin *et al.*, 1975; Hudson *et al.*, 1976).

A variety of studies have utilized X-radiograph revealed coral growth banding for determining environmental relationships or evaluating environmental perturbations. Dodge *et al.* (1974) and Aller and Dodge (1974) studied growth rates of *Montastrea annularis* in Discovery Bay, Jamaica and found that average annual band widths were decreased in specimens from regions of high resuspension of bottom sediments. Loya (1976) found that as sedimentation rates increased on Puerto Rican reefs, coral growth rates decreased. Dodge and Vaisnys (1977) examined the deleterious ecological effects of dredging on corals in Castle Harbor, Bermuda. Hudson (1981) reported a relationship between decreased growth of Florida Keys corals and past dredging events. Dodge and Lang (1983) related decreased coral growth rate on the Flower Gardens Bank reefs of the Western Gulf of Mexico to discharge volumes of the Achafalaya River. Dodge and Brass (1984) found decreased mass growth rates of corals within a relatively polluted harbor in St. Croix, U.S. Virgin Islands compared to corals outside the harbor. Cortes and Risk (1985) found significant inverse correlation between coral growth rates and siltation rates on Costa Rican reefs which they related to increasing sedimentation stress from land deforestation. Tomascik and Sander (1985) found that suspended particulate matter correlated with *Montastrea annularis* skeletal growth up to a certain maximum concentration. After this, reduction of growth occurred due to smothering, reduced light, and reduced zooxanthellae photosynthesis.

1.2.3) Southeast Florida Corals and Coral Reefs

The ecology of southeast Florida offshore coral reefs of Broward and Palm Beach Counties has been described by Goldberg (1973). Additional biological information for Broward County is available in Raymond (1978), Raymond and Antonius (1977), and Goldberg (1984) as well as from a variety of other technical reports. The geology of southeast Florida reefs is given by Duane and Meisburger (1969), Lighty (1977), and Lighty et al. (1978). More geological details on Broward reefs are provided by Raymond (1972).

In general, southeast Florida reefs are considered to be "relict" or fossil structures which are not in an active growth mode, but which are now veneered by a variety of living reef organisms. The area has been characterized as an octocoral-dominated hardground community (Goldberg, 1973; Jaap, 1984). Although, in comparison to reefs of the Caribbean, coral coverage is relatively low, the hermatypic or reef-building coral fauna forms a valuable component of the community structure. These animals form the principal means by which material is actively incorporated into the reef framework, albeit slowly. The corals also provide varying degrees of surface relief to the reefs which, in turn, provides necessary habitats for a variety of fish and shellfish species.

Among common stony coral species on Broward reefs are the star coral Montastrea annularis and the brain coral Diploria labyrinthiformis. Skeletal growth of corals in Broward County is relatively low ranging from 0.35-0.50 cm/yr (this report). Low growth rate may be due primarily to temperature stress from increasingly colder water northward from the Keys. Growth rates of M. annularis have been determined at a variety of reef sites in the Caribbean and Florida. For example, Hudson (1981) reports values ranging from 0.6 to 1.1 cm/yr for specimens from Key Largo National Marine Sanctuary and John Pennekamp Coral Reef State Park.

A perceived cause of sedimentation and turbidity stress to offshore reefs in the southeast Florida area is beach renourishment. Beach renourishment projects typically consist of dredging sand deposits lying between the reefs for redeposition on local beaches. While there are established turbidity guidelines for Class III waters (29 NTU, 50 JTU equivalent) (DER Rules and Regulations), concern is often expressed about both lethal and sublethal effects to reef organisms as a result of mechanical activities and/or sedimentation-turbidity generated by these operations.

2. METHODS AND MATERIALS

2.1) PHYSICAL METHODS

2.1.1) Collection

Specimens of two stony coral species, M. annularis and D. labyrinthiformis, (Figs. 1a, 1b) were collected by the author and members of the Broward County Erosion Prevention District using SCUBA. Reef areas of interest were chosen and later located in the field by shore reference and fathometer trace. Divers then surveyed the reef by swimming with the current. Specimens were loosened from the substrate with a rock hammer or pry bar, put in collection bags (or tied off), and raised to the surface with air bags for vessel pickup. Collected corals ranged in thickness (base to top) from 10-40cm.

Four reef locations (offshore of: Hollywood, Ft. Lauderdale, Pompano Beach, and Deerfield Beach) were surveyed at each of two depths (Mid: approximately 6-10m; Deep: 15-20m). Fig. 2 shows area of survey and collection on each reef. The more offshore rectangles indicate the Deep collection areas. Table 1 lists collection sites, depths, dates of collection, number of specimens obtained, and number of specimens suitable for use from each site and depth.

After survey and preliminary collection, the Ft. Lauderdale Deep site was omitted from the study due to lack of readily available D. labyrinthiformis and heavy bioerosion of existing M. annularis (e.g., see Figs. 4a and 4b). Scarcity of specimens may have been caused in part by anchor damage and anchor chain chafing from large ships awaiting entry into Port Everglades.

For convenience a four letter abbreviation designates each site, depth, and species. The first letter refers to the site (H=Hollywood, F=Ft. Lauderdale, P=Pompano, D=Deerfield). The second letter refers to the depth (M=Mid 9m; D=Deep 18m). The third and fourth letters refer to species (MA=Montastrea annularis; DL=Diploria labyrinthiformis). For example, the Hollywood Mid depth M. annularis collection site is abbreviated to HMMA.

2.1.2) Cutting, X-radiography

Specimens were transported to Nova University Oceanographic Center for analysis. After air drying for 1 week, each coral was sectioned with a diamond bit masonry saw to obtain several (2-8) parallel sided slabs 0.5-0.7cm in thickness (Fig. 3a). Slabs were oriented approximately normal to the upward growth direction of the coral.

Slabs were X-radiographed onto single sheet, paper covered, Kodak AA Industrial X-ray film using a source to subject distance of 1.5m and an exposure of 70 KvP, 10 ma, and times of 10-20 seconds. X-radiograph negatives were developed, dried, and printed onto photographic paper (Fig. 3b).

X-radiograph positives were inspected for quality of revealed density banding. The minimum acceptable time period, 1985-1970, was chosen prior to the commencement of the study. Specimens were rejected from further analysis if banding was indistinct, if the coral could not be viewed because of bioerosion effects (Figs. 4a and 4b), or if the growth record was less than 16 years. For remaining specimens, the X-radiograph showing best annual banding was selected from those available.

* INDEXED BY TRANSECT, THEN AVERAGED

Individual growth bands were assigned years of formation from the known collection date and observation of the band formation at the skeleton growth surface. Methods are discussed in more detail in Dodge and Vaisnys (1980).

2.1.3) Measurements of Growth Bands

To measure coral growth rate, two transects were drawn on each X-radiograph positive in regions of clear banding and typically within approximately 20 degrees of the axis of maximum growth of the coral (Fig. 5). Highly variable growth form of specimens often precluded placing transects on the exact axis of maximum growth.

Band boundaries were marked on each transect at the upper (youngest) portion of the high density band of each annual cycle. Complete bands were assigned appropriate years of formation. Band dimensions were measured with precision calipers to hundredths of a centimeter for each year on each transect. As demonstrated by sequential observations of band type and dimensions at the surface, the high density band of both species appears to begin formation in approximately June and to be completed by August or September. Consequently, a full coral year encompasses roughly August to August. By convention, the named year refers to the most recent calendar year (e.g, coral year of August, 1983 to August, 1984 is designated as coral year 1984).

2.1.4) Data Set Description

The last column in Table 1 lists the numbers of specimens of each species at each site available for analysis. On these corals, yearly growth was measured over at least 1985-1970.

2.2) MATHEMATICAL METHODS AND PROCEDURES

2.2.1) Raw Data

The primary goal of this study was to evaluate differences in coral growth both among sites at particular years and among years within each site in relation to prior beach renourishment projects. Past work and results of this project , however, have demonstrated that the average growth rates of individual corals typically are significantly different among neighbors on a given reef (e.g., Dodge and Lang, 1983; Dodge and Brass, 1984). Absolute growth rate differences among individual corals are a source of variability which complicates higher level analyses. Furthermore, raw growth data of this study contain an additional source of variability. As discussed above, measurement transects could not always be placed in the same relative position on each coral.

Nevertheless, to provide an overview of site characteristics and to evaluate the importance of individual growth differences, average growth rates of the two coral species were calculated and compared among sites.

2.2.2) Normalization

Normalized or index growth data were used to remove complicating effects of differing specimen mean growth and/or of transect placement. Index data values were created by dividing yearly raw data growth measurements of each transect by the appropriate 16 year (1985-1970) transect mean. 1985-1970 was chosen as the normalization period because it was the longest time span common to all measured corals. Graphic and statistical site and year comparisons were conducted with index data.

2.2.3) Master Chronologies

For evaluation of time patterns of growth, master index chronologies were constructed for collection sites by depth and species. A summary or whole coral index chronology for each coral was initially calculated by averaging the index values of the two transects by year. Master chronologies were then calculated by averaging by year all desired whole coral index values of the site or larger groupings. Figs. 7(a-d), 8(a,b), and 9(a,b) provide examples.

2.2.4) Environmental Data

Miami Beach Tide Station monthly mean sea surface temperature and water density (corrected to 15 degrees centigrade) were obtained from NOAA. Data covered 1980-1956 for temperature and 1981-1954 for water density. No long term environmental time series data were available from nearshore locations in Broward County.

2.2.5) Statistical Analyses: ANOVA and SNK

A variety of statistical tests were performed to summarize and interpret the large amount of coral growth data. The standard statistical significance level of at least $p<.05$ (95% probability) was employed. For extra confidence, the $p<.01$ (99%

probability) level was used in some cases.

1) Significant differences among raw data site average growth rates were tested by ANOVA (one-way analysis of variance, 3 level nested) (Sokal and Rohlf, 1981). Specific site differences were isolated by the SNK test (Zar, 1974).

2) Differences among site mean index growth values at particular years or groups of years were tested with one-way nested ANOVA followed by the SNK test to isolate specific site differences.

3) Differences among yearly index means within each particular site were tested by ANOVA (one-way nested). The SNK test was used to determine which years significantly differed.

4) Similarities among the time patterns of normalized coral growth were assessed by correlation coefficients calculated over specified time periods among the chronologies of sites and larger groupings.

5) Available environmental time series (e.g., water temperature and density) were compared to coral growth master chronology time series by correlation analysis.

3. RESULTS AND DISCUSSION

3.1) RAW DATA: SITE COMPARISONS

Fig. 6 depicts average growth rate (cm/yr) of the two coral species at each site for 1985-1970. Table 2 provides detailed results. In general, southern Mid (9m) depth specimens had higher rates of growth than northern counterparts for M. annularis. In the southern collection sites, Mid (9m) depth growth of both species tended to be greater than Deep (18m) depth growth.

Differences among the average growth rates of corals at each of the seven sites (including Mid and Deep) were tested by one-way ANOVA for each species. The three level nested design evaluated differences among the main grouping of sites, the subgroupings of corals within sites, and the subsubgroupings of years within corals, each with two replications. ANOVA results indicated significant differences for all categories. SNK testing isolated specific site differences. Results are summarized in Table 3 and described below.

Hollywood Mid M. annularis corals (HMMA) had significantly greater mean growth than corals of all other sites at either depth. Growth of Ft. Lauderdale Mid site (FMMA) corals was significantly greater than that of Pompano Deep (PDMA) and Hollywood Deep (HDMA) sites respectively. There were no other significant differences among sites for M. annularis.

D. labyrinthiformis corals from the Hollywood Mid site (HMDL) had significantly greater mean growth rate than that of the lowest growth site, Hollywood Deep (HDDL). There were no other significant differences among sites for this species.

As noted, each ANOVA also indicated significant differences among the means of individual corals within sites. This result justifies the following use of index growth values for reduction of variability and increased statistical precision.

3.2) NORMALIZED DATA: SITE COMPARISONS

3.2.1) Site Chronologies and Correlation Analysis

Chronologies

In order to visualize coral growth changes and patterns over time, it is helpful to refer to graphs of averaged index values or master chronologies. Master chronologies emphasize the common variation of grouped corals by filtering out individual variability. Figs. 7 (a-d) illustrate the master chronologies of each site by depth and species. All chronologies are plotted over 1985-1960. Figs. 8a and 8b provide alternative combinations showing each of the Mid and Deep depth site master chronologies by species group. Fig. 9a depicts the grand master chronologies for each species-depth grouping. Fig. 9b depicts the grand master for all corals of each species.

It is readily apparent that there are similarities among the time patterns of site chronologies. Particularly evident are the common growth depression in 1970 and growth elevations in 1981 and 1975-1977. There are also obvious deviations. Details of correlation among sites are discussed below.

Correlations

Correlation analysis was used to quantify similarities of the master chronologies. Product moment correlation coefficients for each pair of site master chronologies over 1985-1970 are presented in Table 4. At the bottom of the table are correlations between master chronologies of all Mid depth, all Deep depth, and all corals for both MA and DL.

The results of Table 4 (1985-1970) show many significant correlations between site masters even at the p<.05 level. The average correlations of MA site groupings are greater than the average of DL site groupings (see also Figs. 8a and 8b). For the grand master chronologies (bottom of table) correlation between MA Mid and Deep corals is greater than for Mid and Deep DL (see also Fig. 9a). Correlation is higher between species at the Mid depth than at the Deep depth. The grand master chronologies of all MA and all DL are highly correlated (see also Fig. 9b).

Table 5 provides correlation coefficients over the longer 1985-1960 time period. Index values for these masters were calculated using the 1985-1960 raw growth average for consistency. This data set may not be as accurate as the data set for 1985-1970 because all corals did not contain measurements over the entire 1985-60 time period. Therefore, years older than 1970 may have fewer corals for averaging into the master.

The results of Table 5 (1985-1960) are similar to those of Table 4. Average correlations of MA site groupings are greater than the average of DL site groupings with the exception of the Deep sites (see also Figs. 8a and 8b). For both species the Mid depth average correlation is higher than the Deep depth average. For the grand master chronologies (bottom of table) correlation between MA Mid and Deep corals is greater than for Mid and Deep

DL (see also Fig. 9a). Correlation is similar between species at both depths. The grand master chronologies for all MA and all DL are highly correlated (see also Fig. 9b).

3.2.2) Results: Site Comparisons; Relationships to Beach Renourishment Effects

Table 6 presents dates, durations, and sediment volumes of past Broward County beach renourishment projects. Also listed are potentially affected coral collection sites and growth years.

Many beach projects were conducted in the summer months. This season is coincident with formation of the dense band portion of the annual coral skeletal growth cycle. In these cases, therefore, at least two single years of effect are possible: the one during which renourishment began, and the one in which renourishment ended. The year in Table 6 designated by * is of primary interest because effects at the end of and subsequent to the project might be expected to have been recorded in this time period. The next following single year is added for extra analysis. Sets of possibly affected double years and triple years are also presented.

For data sets of each coral species (*M. annularis* and *D. labyrinthiformis*), one-way nested ANOVA was conducted to assess differences among site means at specific years or year groupings. SNK testing was used to specify the site differences. Table 7 summarizes the statistical results (grouped by single, double, and triple year tests). Where significant site differences were revealed by ANOVA, SNK results are given in matrix form.

A second kind of analysis allowed examination of significant differences <u>among normalized yearly means within sites</u>. One-way ANOVA was conducted on the 1985-1970 data of each species and site. SNK testing was used to isolate the specific significant differences. If a certain year corresponding with beach renourishment shows statistically depressed growth, and <u>if that difference is supported by other tests</u> (e.g., the among sites analysis), the among year test can provide additional information concerning beach renourishment effects. Table 8 summarizes statistical results for differences among years within sites.

Common site growth characteristics, however, must be recognized. The time pattern of coral growth at each site is correlated with other sites. In addition, all sites exhibit significant differences among years. At least some of these differences are common ones. For example, for all but one site (HDDL: Hollywood Deep *D. labyrinthiformis*), growth for year 1970 was the lowest (significantly less than that of all other years, depending upon site). For these reasons, results of statistical analyses among years within sites are probably less powerful than analyses among sites, and they are used only in a supporting role to among sites analyses.

In the following six sections results and discussion for each renourishment project are presented. At the beginning of each section the results recapitulate information in Tables 7 and 8. The reader may wish to skip directly to the discussion of the effects of each renourishment project.

3.2.2.i) Pompano Beach Renourishment

June-Sept., 1970, 1 million cu yds
Pompano Coral Collection Site (PMMA, PDMA, PMDL, PDDL)
Coral Years of Interest: 1970, 1971*, 1972

Among Sites At Particular Years (Table 7)

Single years: For coral years 1970, 1971, and 1972 SNK results revealed for both MA and DL species that growth at Pompano Mid and Deep sites was not significantly different from growth at other sites.

Double years: For coral years 1970-1971, MA growth at Pompano Mid and Deep sites was not significantly different from that of other sites. DL growth at the Pompano Mid site was the second lowest and was significantly less than that at the highest growth Hollywood Deep site. For coral years 1971-1972, there were no significant site differences for either species.

Triple years: For the three coral year groupings of 1970-1971-1972 and 1971-1972-1973, growth of both species at Pompano Mid and Deep sites was not significantly different from growth at other sites.

Among Year Differences Within Sites (Table 8)

Mean growth of Pompano Mid and Deep coral year 1970 is significantly lower than any other year for MA and lower than that of the 3-4 highest years for DL. (It must be noted that 1970 normalized growth within each MA site is significantly less than that any other year or most years. With the exception of Hollywood Mid, this is also true within all DL sites.)

Growth of Pompano Mid and Deep DL coral year 1971 was not significantly different from that of other years. Growth of Pompano Mid DL coral year 1972 was not significantly different from that of other years. Growth of Pompano Deep DL coral year 1972 was the fourth lowest and was significantly less than growth of the highest year (1976).

Discussion

The statistical evidence among sites does not strongly indicate that renourishment affected Pompano corals except that the growth of Pompano Deep DL was significantly depressed in the years 1970-1971. The among year within site analyses support the conclusion that there were little or no effects from the 1970 renourishment project.

3.2.2.ii) Hallandale Beach Renourishment

June-Sept., 1971, 400,000 cu yds
Hollywood Coral Collection Site (HMMA, HDMA, HMDL, HDDL)
Coral Years of Interest: 1971, 1972*, 1973

Among Sites At Particular Years (Table 7)

Single years: For single coral years 1971, 1972, and 1973 there were no significant site differences for either species.

Double years: For coral years 1971-1972 and 1972-1973, there were no significant site differences for either species.

Triple years: For coral years 1971-1972-1973 and 1972-1973-1974, there were no significant site differences for either coral species.

Among Year Differences Within Sites (Table 8)

Coral growth year 1971 had the second to lowest index value for both MA and DL species from the Hollywood Mid site. 1971 Mid MA growth was significantly less than that of the highest six years and was significantly greater than that of lowest year 1970. 1971 Deep MA growth was second highest and significantly greater than that of 1970. For DL, 1971 Mid growth was not significantly different from that of other sites. 1971 DL Deep growth was significantly greater than that of lowest growth year 1979.

1972 Mid MA growth was significantly greater than that of lowest year 1970 and was significantly less than growth of the two highest years 1976 and 1981. 1972 Deep MA growth was significantly greater than that of lowest year 1970. 1972 Mid and Deep DL growth was not significantly different from other years.

1973 Mid MA growth was significantly greater than that of lowest year 1970 and was significantly less than growth of the two highest years 1976 and 1981. 1973 Deep MA growth was significantly greater than that of lowest year 1970. 1973 Mid DL growth was not significantly different from other years. 1973 Deep DL growth was the highest and was significantly greater than that of the lowest year 1979.

Discussion

The among sites analyses for years 1971 and after do not indicate any significant depression in coral growth from the Hallandale renourishment project. This conclusion is supported by the among year within sites analyses.

3.2.2.iii) Hillsboro Beach Renourishment

June-Sept., 1973, 400,000 cu yds
Deerfield Coral Collection Site (DMMA, DDMA, DMDL, DDDL)
Coral Years of Interest: 1973, 1974*, 1975

Among Sites At Particular Years (Table 7)

Single years: For coral years 1973, 1974, and 1975 there were no significant site differences for either coral species.

Double years: For coral years 1973-1974, and 1974-1975, there were no significant site differences for either coral species.

Triple years: For coral years 1973-1974-1975 and 1974-1975-1976, there were no significant site differences for either coral species.

Among Year Differences Within Sites (Table 8)

Normalized mean coral growth of coral year 1973 for Deerfield Mid site MA was the fourth lowest. Growth of this year was significantly less than growth of the highest year (1981) and significantly greater than growth of the lowest year (1970). For Deerfield Deep, MA growth of 1973 was also significantly greater than that of the lowest year 1970. For DL, Deerfield Mid 1973 growth was significantly greater than that of lowest year 1970. For Deerfield Deep, growth of 1973 was not significantly different from that of other years.

For 1974, growth of MA corals of both Deerfield Mid and Deep sites was significantly greater than that of the lowest year (1970). 1974 growth of DL corals of Deerfield Mid was also significantly greater than that of the lowest year (1970).

For 1975 growth of MA and DL corals of both Deerfield Mid and Deep sites was significantly greater than that of the lowest year (1970).

Discussion

The among sites analyses did not suggest detrimental effects from beach renourishment, a conclusion generally supported by the among years analyses. There is little evidence for detrimental growth effects on Deerfield collected corals from the Hillsboro Beach renourishment project.

3.2.2.iv) John U. Lloyd State Recreation Area Beach Renourishment

Sept., 1976 to Feb., 1977, 1.1 million cu yds
Ft. Lauderdale Coral Collection Site (FMMA, FMDL)
Coral Years of Interest: 1977*, 1978

Among Sites At Particular Years (Table 7)

Single years: For coral year 1977 there were no significant site differences for either coral species. For coral year 1978 Ft. Lauderdale Mid MA and DL corals did not exhibit significant site growth differences.

Double years: For coral years 1977-1978, no site differences were evident for either species.

Triple years: For coral years 1977-1978-1979, no site differences were evident for either species.

Among Year Differences Within Sites (Table 8)

1977 growth of Ft. Lauderdale Mid MA and DL was significantly greater than that of the lowest year (1970). 1978 growth of Ft. Lauderdale Mid MA was significantly greater than that of the lowest year (1970). 1978 growth of Ft. Lauderdale Mid DL was not significantly different from that of other years.

Discussion

Neither analysis indicates adverse growth effects on Fort Lauderdale collected corals from the John U. Lloyd State Recreation Area beach renourishment project.

3.2.2.v) Hollywood-Hallandale Beach Renourishment

July-Nov., 1979, 2 million cu yds
Hollywood Coral Collection Site (HMMA, HDMA, HMDL, HDDL)
Possible Coral Years of Interest: 1979, 1980*, 1981

Among Sites At Particular Years (Table 7)

Single years: For coral year 1979 there were no significant site differences for MA; however, DL corals of the Hollywood Deep site exhibited significantly lower normalized growth than that of all other sites. Alternatively, the Hollywood Mid DL site had the second highest growth. For coral years 1980 and 1981, no site differences were evident for either species.

Double years: For coral years 1979-1980 and the species MA, growth at Hollywood collection sites was not significantly different from that at other sites. For the species DL, growth at the Hollywood Deep site was the lowest, significantly less than that at the highest growth site (Deerfield Deep). Hollywood Mid DL growth was second lowest. For the double coral years 1980-1981, there were no significant site differences for either species.

Triple years: For coral years 1979-1980-1981, there were no significant site differences for MA corals. For DL the Hollywood Deep site exhibited lowest normalized growth, significantly different from that of the two highest growth sites (Deerfield Deep and Mid). For the triple coral years 1980-1981-1982, coral species MA exhibited no site differences. DL corals of the Hollywood Deep collection had lowest normalized growth, statistically less than that of the site of highest normalized growth (Deerfield Mid).

Among Year Differences Within Sites (Table 8)

For Hollywood sites and years 1979, 1980, and 1981, MA collections showed growth anomalies. For Mid depth corals, 1979 growth was the fourth lowest and was significantly less than growth of the two highest growth years. Year 1980 had the sixth lowest growth, significantly less than that of the two highest years. Year 1981 was the highest growth year, significantly greater than that of the eight lowest years. For Hollywood Deep MA, 1979 growth was the third lowest and was significantly less than growth of the highest year 1975. Growth in 1981 was significantly greater than that of the lowest year 1970.

Growth of years 1979, 1980, and 1981 did not exhibit statistical differences for the Mid depth DL collections. However, for the Deep DL site, 1979 growth was the lowest and was statistically less than growth of the highest five years. It should be noted that this was the only site in which coral year 1970 was not the lowest growth year. Growth of 1980 and 1981 was not significantly different from that of other years.

Discussion

The statistical analyses indicated depressed growth of Hollywood Deep DL corals in the years of and following Hollywood-Hallandale beach renourishment. This is evident in the one, two, and three year among site analyses and is supported by the among year analyses. The result is suggestive of possible renourishment effects on Hollywood collected corals. This suggestion is weakened, however, by the finding that MA corals at both depths and DL corals at Mid depth did not exhibit depressed growth.

3.2.2.vi) Pompano Beach Renourishment

June-Aug., 1983, 2 million cu yds
Pompano Coral Collection (PMMA, PMDL, PDMA, PDDL)
Coral Years of Interest: 1983, 1984*, 1985

Among Sites At Particular Years (Table 7)

Single years: For coral year 1983, there were no significant site differences for either species. For the single coral year 1984, MA exhibited no significant site differences. For DL at this year, Pompano Mid and Deep site corals exhibited the third and fourth highest normalized growth which was significantly less than that of the highest growth site (Hollywood Mid). For coral year 1985, there were no significant site differences for either species.

Double years: For both species for coral years 1983-1984, the Pompano sites were not significantly different from other sites. For the double coral years 1984-1985, there were no significant site differences for either species.

Triple years: For coral years 1983-1984-1985, growth of both MA and DL Pompano corals exhibited no significant site differences.

Among Year Differences Within Sites (Table 8)

For year 1983 Pompano Mid MA growth was significantly greater than that of the lowest year (1970). Pompano Deep MA growth was also significantly greater than that of the lowest year (1970), but was significantly less than that of the highest year (1981). Pompano Mid DL growth for 1983 did not differ significantly from that of other years. Pompano Deep DL growth was significantly less than that of the highest year (1976).

For year 1984 Pompano Mid MA growth was significantly greater than that of the lowest year (1970). Pompano Deep MA growth was also significantly greater than that of the lowest year (1970), but was significantly less than that of the highest year (1981). Pompano Mid and Deep DL growth was not significantly different from that of other years.

For year 1985 Pompano Mid and Deep MA and DL growth was significantly greater than that of the lowest year (1970).

Discussion

The among sites analyses did not demonstrate significantly different growth at Pompano sites following renourishment. While the among year within site analyses exhibited some differences, there is little evidence from the site growth comparisons of detrimental effects on Pompano collected corals from the second Pompano beach renourishment project.

3.2.3) Environmental Relationships

Miami Beach data consisted of average monthly sea surface temperature and sea water density observations. Because density data had been corrected to a constant temperature of 15 degrees centigrade, it was an equivalent index of salinity. Data coverage was approximately 1980 to 1955. Time series of each parameter were calculated as a selection of 3 month and 6 month combinations for each year. One 12 month series was calculated. For sea surface temperature, Fig. 10a presents monthly averages over the record and Fig. 10b presents seasonal (3 month averages) by year. Figs. 11a and 11b present similar relationships for sea water density.

Grand master chronologies of each species for each depth and for all depths were compared to Miami Beach environmental data time series using correlation analysis. Table 9 presents the product moment correlation coefficients calculated among coral index masters and combined monthly time series data.

Sea surface temperature time series are occasionally correlated with coral growth. This is particularly evident for the JFM (January, February, and March) average. Sea surface density (salinity) time series are usually highly correlated with coral growth with the possible exception of the summer JAS (July, August, and September) months.

The relatively strong and significant positive growth relationship with salinity variations may be representative of a direct salinity-growth effect. Although no direct data is available, it is, however, hard to imagine that absolute salinity changes as recorded at Miami Beach would also occur several miles offshore at depths of 10 and 20m. Alternatively, weather conditions may affect both salinity and coral growth: rainfall may cause salinity to decrease and the lowered light levels associated with rainfall causes coral growth to decrease. Consequently, salinity variations at the beach may represent an index of available light levels at the offshore reefs.

More research (laboratory and *in situ*) is necessary to clarify and quantify these complex relationships. A larger environmental time series data set would also be helpful.

4. SUMMARY AND CONCLUSIONS

Summary

This study was designed to investigate the growth of two species of hermatypic corals at various reef areas in Broward County, Florida. A goal was to evaluate sedimentation/turbidity effects from past beach renourishment projects in terms of depressed coral growth. For those years which corresponded to periods of beach renourishment projects, statistical analyses were conducted to compare normalized coral growth among sites.

The statistical evidence for those corals and sites examined indicates that, in general, years of and subsequent to Broward County beach renourishment projects do not correspond to times of lowered growth of currently living offshore reef corals.

A possible exception is the Hollywood-Hallandale renourishment project of 1979 in which one coral species (*D. labyrinthiformis*) from one site and depth (Hollywood, 18m) exhibited significantly lower normalized growth in comparison to other sites. However, this may not represent effects from the renourishment project. At the Hollywood site the other coral species (*M. annularis*) from both depths and *D. labyrinthiformis* from Mid depth (9m) did not exhibit significantly lowered growth in comparison to other sites.

Site averages of absolute coral growth indicated that southern 9m depth specimens had higher rates of growth than northern counterparts for *M. annularis*. In the southern collection sites, 9m depth growth of both species tended to be greater than 18m depth growth. The results might be explained by slightly warmer water temperature to the south and enhanced light availability at shallower depths.

Graphic comparisons and correlation analyses indicated that the time pattern of coral growth exhibits relatively high variability and is similar between sites, species, and depths. This suggests the existence of a common, apparently natural, forcing function of the environment to which the corals are responding. Comparison of time series of coral growth data to recorded environmental variables revealed an occasional positive variation with temperature and a strong positive relation with salinity. This may be a direct effect of decreased coral growth caused by decreased salinity. Alternatively, the relationship may represent an indirect coral response to salinity. Low salinity is possibly representative of rainy, cloudy, low light conditions which in turn may act to depress coral growth rates.

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TABLE 1 CORAL COLLECTION INFORMATION BY SITE, DEPTH, AND SPECIES

SITE	DEPTH	DATES	CORAL SPECIES	NUMBER CORALS COLL.	NUMBER CORALS >16 YRS
HOLLYWOOD	MID	12-Dec-85			
	9 M	22-Feb-86			
(HMMA)		30-Oct-86	M.a.	20	14
(HMDL)		12-Dec-85			
		22-Feb-86	D.l.	15	14
HOLLYWOOD	DEEP	04-Feb-85			
(HDMA)	18 M	20-Oct-86	M.a.	23	11
(HDDL)		04-Feb-85	D.l.	14	10
FT.LAUDERDALE					
(FMMA)	MID	22-Apr-86	M.a.	13	11
	9 M				
(FMDL)		22-Apr-86	D.l.	10	10
FT. LAUDERDALE					
(FDMA)	DEEP	25-Apr-86	M.a.	14	0
	18 M				
(FDDL)		25-Apr-86	D.l.	0	0
POMPANO	MID				
(PMMA)	9 M	09-Jun-86	M.a.	16	10
(PMDL)		09-Jun-86	D.l.	13	13
POMPANO	DEEP				
(PDMA)	18 M	24-Jul-86	M.a.	19	10
(PDDL)		24-Jul-86	D.l.	15	11
DEERFIELD	MID				
(DMMA)	9 M	06-Aug-86	M.a.	13	10
(DMDL)		06-Aug-86	D.l.	11	10
DEERFIELD	DEEP				
(DDMA)	18 M	06-Aug-86			
		17-Nov-86	M.a.	15	10
(DDDL)		06-Aug-86			
		17-Nov-86	D.l.	12	10
TOTAL				223	154

TABLE 2

AVERAGE GROWTH RATE OF CORALS AT EACH SITE (CM/YR)
OVER THE PERIOD 1985-1970

(Refer to Table 1 for Site abbreviations)

Site	HMMA	FMMA	PMMA	DMMA
Mean	0.490	0.411	0.369	0.343
SD	0.166	0.156	0.124	0.130
N	448	352	320	320
N Corals	14	11	10	10

Site	HMDL	FMDL	PMDL	DMDL
Mean	0.514	0.506	0.504	0.453
SD	0.108	0.110	0.101	0.100
N	448	320	416	320
N Corals	14	10	13	10

Site	HDMA	FDMA	PDMA	DDMA
Mean	0.332	NOT	0.335	0.346
SD	0.088	SAMPLED	0.101	0.086
N	352		320	320
N Corals	11		10	10

Site	HDDL	FDDL	PDDL	DDDL
Mean	0.425	NOT	0.426	0.463
SD	0.091	SAMPLED	0.091	0.082
N	320		352	320
N Corals	10		11	10

TABLE 3

RESULTS OF STATISTICAL COMPARISONS (SNK TEST) FOR RAW DATA

(Site codes consists of two letters. The first refers to the location: H=Hollywood, F=Ft. Lauderdale, P=Pompano, D=Deerfield; the second refers to the depth: M=Mid, D=Deep.)

M. annularis SITES
(Sites arranged from lowest to highest:
left to right, top to bottom)
* indicates significant difference at least at p<.05

	HD	PD	DM	DD	PM	FM	HM
HD	--					*	*
PD		--				*	*
DM			--				*
DD				--			*
PM					--		*
FM	*	*				--	*
HM	*	*	*	*	*	*	--

D. labyrinthiformis SITES
(Sites arranged from lowest to highest:
left to right, top to bottom)
* indicates significant difference at least at p<.05

	HD	PD	DM	DD	PM	FM	HM
HD	--						*
PD		--					
DM			--				
DD				--			
PM					--		
FM						--	
HM	*						--

TABLE 4

CORRELATION ANALYSES OF MASTER CHRONOLOGIES FOR 1985-1970

MATRIX OF CORRELATION COEFFICIENTS (r)
BETWEEN INDIVIDUAL SITE MASTER CHRONOLOGIES
1985-70 DATA, N=16, DF=14 (for p<.05, r>.497; for p<.01, r>.624)
(1985-1970 means used for index calculation)

	HMMA	FMMA	PMMA	DMMA	HDMA	PDMA	DDMA	HMDL	FMDL	PMDL	DMDL	HDDL	PDDL	DDDL
HMMA	----	0.83	0.82	0.87	0.61	0.85	0.60	0.77	0.59	0.83	0.77	0.17	0.69	0.50
FMMA	0.83	----	0.87	0.78	0.49	0.87	0.53	0.69	0.58	0.68	0.78	0.04	0.53	0.40
PMMA	0.82	0.87	----	0.85	0.69	0.93	0.80	0.47	0.64	0.64	0.83	0.21	0.60	0.52
DMMA	0.87	0.78	0.85	----	0.57	0.90	0.69	0.64	0.55	0.71	0.86	-0.06	0.43	0.52
HDMA	0.61	0.49	0.69	0.57	----	0.62	0.81	0.19	0.81	0.43	0.43	0.60	0.55	0.50
PDMA	0.85	0.87	0.93	0.90	0.62	----	0.76	0.63	0.58	0.67	0.83	0.10	0.52	0.50
DDMA	0.60	0.53	0.80	0.69	0.81	0.76	----	0.12	0.57	0.49	0.60	0.51	0.50	0.51
HMDL	0.77	0.69	0.47	0.64	0.19	0.63	0.12	----	0.26	0.57	0.46	-0.21	0.31	0.05
FMDL	0.59	0.58	0.64	0.55	0.81	0.58	0.57	0.26	----	0.50	0.40	0.35	0.54	0.41
PMDL	0.83	0.68	0.64	0.71	0.43	0.67	0.49	0.57	0.50	----	0.69	0.27	0.68	0.58
DMDL	0.77	0.78	0.83	0.86	0.43	0.83	0.60	0.46	0.40	0.69	----	-0.05	0.45	0.62
HDDL	0.17	0.04	0.21	-0.06	0.60	0.10	0.51	-0.21	0.35	0.27	-0.05	----	0.59	0.33
PDDL	0.69	0.53	0.60	0.43	0.55	0.52	0.50	0.31	0.54	0.68	0.45	0.59	----	0.64
DDDL	0.50	0.40	0.52	0.52	0.50	0.50	0.51	0.05	0.41	0.58	0.62	0.33	0.64	----

AVERAGE INTERNAL CORRELATION

	Mean	N		Mean	N
ALL MA SITES	0.75	21	ALL DL SITES	0.40	21
MA MID SITES	0.84	6	DL MID SITES	0.48	6
MA DEEP SITES	0.73	3	DL DEEP SITES	0.52	3

AVE ALL SITES 0.534 N=49

MATRIX OF CORRELATION COEFFICIENTS
BETWEEN GRAND MASTER CHRONOLOGIES OVER 1985-1970 PERIOD
1985-70 DATA, N=16, DF=14 (for p<.05, r>.497; for p<.01, r>.624)
(using 1985-70 for index mean calculation)

	MID MA	DEEP MA	ALL MA	MID DL	DEEP DL	ALL DL
MAMID	--	0.82	0.97	0.95	0.50	0.86
MADEEP	0.82	--	0.93	0.72	0.63	0.79
MAALL	0.97	0.93	--	0.91	0.57	0.87
DLMID	0.95	0.72	0.91	--	0.50	0.89
DLDEEP	0.50	0.63	0.57	0.50	--	0.83
DLALL	0.86	0.79	0.87	0.89	0.83	--

TABLE 5

CORRELATION ANALYSES OF MASTER CHRONOLOGIES FOR 1985-1960

MATRIX OF CORRELATION COEFFICIENTS (r)
BETWEEN INDIVIDUAL SITE MASTER CHRONOLOGIES OVER 1985-1960 PERIOD
N=26, DF=24 (for p<.05, r>.388; for p<.01, r>.496)
(1986-1960 means used for index calculation)

	HMMA	FMMA	PMMA	DMMA	HDMA	PDMA	DDMA	HMDL	FMDL	PMDL	DMDL	HDDL	PDDL	DDDL
HMMA	---	0.79	0.76	0.83	0.50	0.79	0.38	0.71	0.51	0.71	0.69	0.30	0.64	0.69
FMMA	0.79	---	0.83	0.69	0.48	0.76	0.42	0.61	0.40	0.50	0.74	0.18	0.61	0.57
PMMA	0.76	0.83	---	0.74	0.69	0.69	0.66	0.29	0.23	0.29	0.59	0.28	0.59	0.55
DMMA	0.83	0.69	0.74	---	0.55	0.81	0.61	0.48	0.42	0.44	0.73	0.14	0.54	0.67
HDMA	0.50	0.48	0.69	0.55	---	0.31	0.79	-0.02	0.13	-0.05	0.33	0.56	0.57	0.56
PDMA	0.79	0.76	0.69	0.81	0.31	---	0.42	0.63	0.61	0.62	0.72	0.17	0.53	0.55
DDMA	0.38	0.42	0.66	0.61	0.79	0.42	---	-0.12	-0.03	-0.15	0.38	0.47	0.57	0.43
HMDL	0.71	0.61	0.29	0.48	-0.02	0.63	-0.12	---	0.57	0.83	0.58	0.08	0.29	0.49
FMDL	0.51	0.40	0.23	0.42	0.13	0.61	-0.03	0.57	---	0.66	0.45	0.28	0.34	0.42
PMDL	0.71	0.50	0.29	0.44	-0.05	0.62	-0.15	0.83	0.66	---	0.63	0.23	0.35	0.53
DMDL	0.69	0.74	0.59	0.73	0.33	0.72	0.38	0.58	0.45	0.63	---	0.18	0.57	0.68
HDDL	0.30	0.18	0.28	0.14	0.56	0.17	0.47	0.08	0.28	0.23	0.18	---	0.62	0.46
PDDL	0.64	0.61	0.59	0.54	0.57	0.53	0.57	0.29	0.34	0.35	0.57	0.62	---	0.67
DDDL	0.69	0.57	0.55	0.67	0.56	0.55	0.43	0.49	0.42	0.53	0.68	0.46	0.67	---

AVERAGE INTERNAL CORRELATION

	MEAN	N		MEAN	N
MA ALL SITES	0.643	21	DL ALL SITES	0.472	21
MA MID SITES	0.[illegible]	6	DL MID SITES	0.620	6
MA DEEP SITES	0.508	3	DL DEEP SITES	0.586	3

MATRIX OF CORRELATION COEFFICIENTS
BETWEEN GRAND MASTER CHRONOLOGIES OVER 1985-1960 PERIOD
N=26, DF=24 (for p<.05, r>.388; for p<.01, r>.496)
(1986-1960 means used for index calculation)

	MID MA	DEEP MA	ALL MA	MID DL	DEEP DL	ALL DL
MID MA	---	0.73	0.95	0.68	0.65	0.78
DEEP MA	0.73	---	0.91	0.17	0.69	0.42
ALL MA	0.95	0.91	---	0.49	0.71	0.67
MID DL	0.68	0.17	0.49	---	0.49	0.93
DEEP DL	0.65	0.69	0.71	0.49	---	0.77
ALL DL	0.78	0.42	0.67	0.93	0.77	---

TABLE 6

RENOURISHMENT PROJECTS, DURATIONS, POTENTIALLY AFFECTED CORAL COLLECTION SITES AND YEARS AFFECTED

RENOURISHMENT PROJECT	APPROX. DATES	SEDIMENT VOLUME (CU YDS)	CORAL COLL. SITE	POSSIBLE CORAL YEARS AFFECTED: SINGLE YRS	DOUBLE YEARS	TRIPLE YEARS
POMPANO	JUN-SEP,1970	1M	P	1970	70-71	70-71-72
				1971 *	71-72	71-72-73
				1972		
HALLANDALE	JUN-SEP,1971	400K	H	1971	71-72	71-72-73
				1972 *	72-73	72-73-74
				1973		
HILLSBORO BEACH	JUN-SEP,1973	400K	D	1973	73-74	73-74-75
				1974 *	74-75	74-75-76
				1975		
LLOYD PARK	SEP,1976 TO FEB,1977	1.1M	F	1977 *	77-78	77-78-79
				1978		
HOLLYWOOD-HALLANDALE	JUL,1979-NOV,1979	2M	H	1979	79-80	79-80-81
				1980 *	80-81	80-81-82
				1981		
POMPANO	JUN-AUG,1983	2M	P	1983	83-84	83-84-85
				1984 *	84-85	
				1985		

(CORAL YEARS RUN FROM APPROXIMATELY JULY-AUG OF PRECEEDING CALENDAR YEAR TO JULY-AUG OF CALENDAR YEAR)

(* INDICATES SINGLE OR GROUPS OF YEARS MOST LIKELY AFFECTED)

(Site codes refer to collection sites: H=Hollywood, F=Ft. Lauderdale, P=Pompano, D=Deerfield)

TABLE 7

DIFFERENCES AMONG SITES AT SINGLE, DOUBLE AND TRIPLE YEARS

RESULTS: ONE WAY ANOVA (NESTED) AND SNK TESTING OF SITE DIFFERENCES AT SINGLE YEARS (INDEX DATA)

NS indicates ANOVA revealed No Significant site differences.

When a matrix of site comparisons is present, an * indicates significant difference between the indicated sites at least at the p<.05 level. (Site codes consist of two letters. The first refers to the location: H=Hollywood, F=Ft. Lauderdale, P=Pompano, D=Deerfield; the second refers to the depth: M=Mid, D=Deep.)
Sites are listed from lowest to highest mean: left to right and top to bottom.

M. annularis
1970

	FM	HM	DM	PM	PD	DD	HD
FM						*	*
HM							*
DM							
PM							
PD							
DD	*						
HD	*	*					

M. annularis
1971
NS

M. annularis
1972
NS

M. annularis
1973
NS

M. annularis
1974
NS

M. annularis
1975
NS

D. labyrinthiformis
1970

	DM	FM	PM	PD	HM	DD	HD
DM							*
FM							
PM							
PD							
HM							
DD							
HD	*						

D. labyrinthiformis
1971
NS

D. labyrinthiformis
1972
NS

D. labyrinthiformis
1973
NS

D. labyrinthiformis
1974
NS

D. labyrinthiformis
1975
NS

TABLE 7 CONTINUED

<u>M. annularis</u>
1976
NS

<u>D. labyrinthiformis</u>
1976
NS

<u>M. annularis</u>
1977
NS

<u>D. labyrinthiformis</u>
1977
NS

<u>M. annularis</u>
1978
NS

<u>D. labyrinthiformis</u>
1978

	HD	HM	PD	PM	FM	DD	DM
HD							*
HM							
PD							
PM							
FM							
DD							
DM	*						

<u>M. annularis</u>
1979
NS

<u>D. labyrinthiformis</u>
1979

	HD	DM	PM	PD	DD	HM	FM
HD		*	*	*	*	*	*
DM	*						
PM	*						
PD	*						
DD	*						
HM	*						
FM	*						

<u>M. annularis</u>
1980
NS

<u>D. labyrinthiformis</u>
1980
NS

<u>M. annularis</u>
1981
NS

<u>D. labyrinthiformis</u>
1981
NS

<u>M. annularis</u>
1982
NS

<u>D. labyrinthiformis</u>
1982

	PD	HD	FM	DD	HM	PM	DM
PD							*
HD							
FM							
DD							
HM							
PM							
DM	*						

TABLE 7 CONTINUED

M. annularis
1983
NS

D. labyrinthiformis
1983
NS

M. annularis
1984
NS

D. labyrinthiformis
1984

	DD	DM	HD	PD	PM	FM	HM
DD							*
DM							*
HD							*
PD							*
PM							*
FM							*
HM	*	*	*	*	*	*	

M. annularis
1985
NS

D. labyrinthiformis
1985
NS

TABLE 7 CONTINUED

RESULTS: ONE WAY ANOVA (NESTED) AND SNK TESTING
SITE DIFFERENCES AT DOUBLE YEAR GROUPINGS (INDEX DATA)

NS indicates ANOVA revealed No Significant site differences.

When a matrix of site comparisons is present, an * indicates significant difference between the indicated sites at least at the $p<.05$ level. (Site codes consist of two letters. The first refers to the location: H=Hollywood, F=Ft. Lauderdale, P=Pompano, D=Deerfield; the second refers to the depth: M=Mid, D=Deep.)
Sites are listed from lowest to highest mean: left to right and top to bottom.

1970-1971
M. annularis

	HM	FM	DM	PM	PD	DD	HD
HM							*
FM							*
DM							*
PM							
PD							
DD							
HD	*	*	*				

1970-1971
D. labyrinthiformis

	DM	PM	HM	DD	PD	FM	HD
DM							*
PM							*
HM							*
DD							*
PD							
FM							
HD	*	*	*	*			

1971-1972
M. annularis
NS

1971-1972
D. labyrinthiformis
NS

1972-1973
M. annularis
NS

1972-1973
D. labyrinthiformis
NS

1973-1974
M. annularis
NS

1973-1974
D. labyrinthiformis
NS

1974-1975
M. annularis
NS

1974-1975
D. labyrinthiformis
NS

1977-1978
M. annularis
NS

1977-1978
D. labyrinthiformis
NS

TABLE 7 CONTINUED

1979-1980
M. annularis

	DD	HD	PM	HM	DM	PD	FM
DD					*	*	*
HD							
PM							
HM							
DM	*						
PD	*						
FM	*						

1979-1980
D. labyrinthiformis

	HD	HM	PD	PM	FM	DM	DD
HD							*
HM							
PD							
PM							
FM							
DM							
DD	*						

1980-1981
M. annularis
NS

1980-1981
D. labyrinthiformis
NS

1983-1984
M. annularis

	DD	HD	DM	PM	PD	HM	FM
DD						*	*
HD							
DM							
PM							
PD							
HM	*						
FM	*						

1983-1984
D. labyrinthiformis

	DD	HD	PD	DM	PM	FM	HM
DD							*
HD							*
PD							
DM							
PM							
FM							
HM	*	*					

1984-1985
M. annularis
NS

1984-1985
D. labyrinthiformis
NS

RESULTS: ONE WAY ANOVA (NESTED) AND SNK TESTING
SITE DIFFERENCES AT TRIPLE YEAR GROUPINGS (INDEX DATA)

NS indicates ANOVA revealed No Significant site differences.

When a matrix of site comparisons is present, an * indicates significant difference between the indicated sites at least at the $p<.05$ level. (Site codes consist of two letters. The first refers to the location: H=Hollywood, F=Ft. Lauderdale, P=Pompano, D=Deerfield; the second refers to the depth: M=Mid, D=Deep.)
Sites are listed from lowest to highest mean: left to right and top to bottom.

1970-1971-1972
M. annularis

	HM	FM	DM	PD	PM	HD	DD
HM						*	*
FM							
DM							
PD							
PM							
HD	*						
DD	*						

1970-1971-1972
D. labyrinthiformis
NS

1971-1972-1973
M. annularis
NS

1971-1972-1973
D. labyrinthiformis
NS

1973-1974-1975
M. annularis
NS

1973-1974-1975
D. labyrinthiformis
NS

1974-1975-1976
M. annularis
NS

1974-1975-1976
D. labyrinthiformis
NS

1977-1978-1979
M. annularis
NS

1977-1978-1979
D. labyrinthiformis
NS

TABLE 7 CONTINUED

1979-1980-1981
M. annularis
NS

1979-1980-1981
D. labyrinthiformis

	HD	FM	PM	PD	HM	DD	DM
HD						*	*
FM							
PM							
PD							
HM							
DD	*						
DM	*						

1980-1981-1982
M. annularis
NS

1980-1981-1982
D. labyrinthiformis

	HD	PD	FM	HM	PM	DD	DM
HD							*
PD							
FM							
HM							
PM							
DD							
DM	*						

1983-1984-1985
M. annularis

	DD	HD	DM	PM	PD	HM	FM
DD							*
HD							
DM							
PM							
PD							
HM							
FM	*						

1983-1984-1985
D. labyrinthiformis

	DD	HD	FM	DM	PD	PM	HM
DD							*
HD							
FM							
DM							
PD							
PM							
HM	*						

TABLE 8

DIFFERENCES AMONG YEARS WITHIN SITES

RESULTS OF WITHIN SITE ANOVA/SNK

An * indicates significant difference between the indicated year means at least at the p<.05 level. Years for the matrices are listed from lowest to highest mean value: left to right and top to bottom.

HMMA (HOLLYWOOD MID *M. annularis*)

	70	71	83	79	78	80	74	73	72	84	82	77	85	75	76	81
70	—	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
71	*	—									*	*	*	*	*	*
83	*		—											*	*	*
79	*			—											*	*
78	*				—										*	*
80	*					—									*	*
74	*						—								*	*
73	*							—							*	*
72	*								—						*	*
84	*									—						
82	*	*									—					
77	*	*										—				
85	*	*											—			
75	*	*	*											—		
76	*	*	*	*	*	*	*	*	*						—	
81	*	*	*	*	*	*	*	*	*							—

HDMA (HOLLYWOOD DEEP *M. annularis*)

	70	83	79	80	85	84	78	72	82	73	76	81	74	77	71	75
70	—							*	*	*	*	*	*	*	*	*
83		—														*
79			—													*
80				—												
85					—											
84						—										
78							—									
72	*							—								
82	*								—							
73	*									—						
76	*										—					
81	*											—				
74	*												—			
77	*													—		
71	*														—	
75	*	*	*													—

TABLE 8 CONTINUED: DIFFERENCES AMONG YEARS WITHIN SITES

HMDL (HOLLYWOOD MID *D. labyrinthiformis*)

	70	71	78	73	72	80	83	74	77	76	75	79	85	82	81	84
70	--															*
71		--														
78			--													
73				--												
72					--											
80						--										
83							--									
74								--								
77									--							
76										--						
75											--					
79												--				
85													--			
82														--		
81															--	
84	*															--

HDDL (HOLLYWOOD DEEP *D. labyrinthiformis*)

	79	83	84	82	78	80	81	70	72	85	77	75	74	71	76	73
79	--											*	*	*	*	*
83		--													*	*
84			--													
82				--												
78					--											
80						--										
81							--									
70								--								
72									--							
85										--						
77											--					
75	*											--				
74	*												--			
71	*													--		
76	*	*													--	
73	*	*														--

TABLE 8 CONTINUED: DIFFERENCES AMONG YEARS WITHIN SITES

FMMA (FT LAUDERDALE MID *M. annularis*)

	70	73	79	83	74	82	71	75	77	72	76	78	80	84	81	85
70	--	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
73	*	--											*	*	*	*
79	*		--													*
83	*			--												*
74	*				--											
82	*					--										
71	*						--									
75	*							--								
77	*								--							
72	*									--						
76	*										--					
78	*											--				
80	*	*											--			
84	*	*												--		
81	*	*													--	
85	*	*	*	*												--

FMDL (FT. LAUDERDALE MID *D. labyrinthiformis*)

	70	85	78	84	83	82	73	81	80	72	79	74	76	75	77	71
70	--												*	*	*	*
85		--														
78			--													
84				--												
83					--											
82						--										
73							--									
81								--								
80									--							
72										--						
79											--					
74												--				
76	*												--			
75	*													--		
77	*														--	
71	*															--

TABLE 8 CONTINUED: DIFFERENCES AMONG YEARS WITHIN SITES

PMMA (POMPANO MID M. annularis)

	70	79	73	83	84	74	80	82	77	72	85	71	75	76	78	81
70	--	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
79	*	--														
73	*		--													
83	*			--												
84	*				--											
74	*					--										
80	*						--									
82	*							--								
77	*								--							
72	*									--						
85	*										--					
71	*											--				
75	*												--			
76	*													--		
78	*														--	
81	*															--

PDMA (POMPANO DEEP M. annularis)

	70	83	79	73	77	74	72	71	78	84	75	85	76	82	80	81
70	--	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
83	*	--														*
79	*		--													*
73	*			--												*
77	*				--											
74	*					--										
72	*						--									
71	*							--								
78	*								--							
84	*									--						
75	*										--					
85	*											--				
76	*												--			
82	*													--		
80	*														--	
81	*	*	*	*												--

TABLE 8 CONTINUED: DIFFERENCES AMONG YEARS WITHIN SITES

PMDL (POMPANO MID *D. labyrinthiformis*)

	70	71	84	78	72	83	79	73	75	77	81	80	74	85	82	76
70	--													*	*	*
71		--														
84			--													
78				--												
72					--											
83						--										
79							--									
73								--								
75									--							
77										--						
81											--					
80												--				
74													--			
85	*													--		
82	*														--	
76	*															--

PDDL (POMPANO DEEP *D. labyrinthiformis*)

	70	82	83	72	84	78	79	80	71	74	73	81	77	75	85	76
70	--												*	*	*	*
82		--														*
83			--													*
72				--												*
84					--											*
78						--										
79							--									
80								--								
71									--							
74										--						
73											--					
81												--				
77	*												--			
75	*													--		
85	*														--	
76	*	*	*	*	*											--

TABLE 8 CONTINUED: DIFFERENCES AMONG YEARS WITHIN SITES

DMMA (DEERFIELD MID M. annularis)

	70	83	71	73	85	74	79	80	84	77	72	75	76	78	82	81
70	--	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
83	*	--														*
71	*		--													*
73	*			--												*
85	*				--											*
74	*					--										
79	*						--									
80	*							--								
84	*								--							
77	*									--						
72	*										--					
75	*											--				
76	*												--			
78	*													--		
82	*														--	
81	*	*	*	*	*											--

DDMA (DEERFIELD DEEP M. annularis)

	70	83	79	84	80	85	77	78	74	73	82	75	71	76	72	81
70	--				*	*	*	*	*	*	*	*	*	*	*	*
83		--					*	*	*	*	*	*	*	*	*	*
79			--									*	*	*	*	*
84				--									*	*	*	*
80	*				--											*
85	*					--										*
77	*	*					--									
78	*	*						--								
74	*	*							--							
73	*	*								--						
82	*	*									--					
75	*	*	*									--				
71	*	*	*	*									--			
76	*	*	*	*										--		
72	*	*	*	*											--	
81	*	*	*	*	*	*										--

TABLE 8 CONTINUED: DIFFERENCES AMONG YEARS WITHIN SITES

DMDL (DEERFIELD MID <u>D. labyrinthiformis</u>)

	70	84	71	74	83	79	72	75	73	76	77	80	85	82	78	81
70	--	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
84	*	--														
71	*		--													
74	*			--												
83	*				--											
79	*					--										
72	*						--									
75	*							--								
73	*								--							
76	*									--						
77	*										--					
80	*											--				
85	*												--			
82	*													--		
78	*														--	
81	*															--

DDDL (DEERFIELD DEEP <u>D. labyrinthifromis</u>)

	70	83	84	72	71	82	85	77	79	74	81	78	76	73	75	80
70	--														*	*
83		--													*	*
84			--												*	*
72				--												
71					--											
82						--										
85							--									
77								--								
79									--							
74										--						
81											--					
78												--				
76													--			
73														--		
75	*	*	*												--	
80	*	*	*													--

TABLE 9

CORRELATION ANALYSIS OF CORAL MASTER CHRONOLOGIES WITH ENVIRONMENTAL TIME SERIES

1980-1960 CORRELATION COEFFICIENTS n=20 (for $p<.01$, $r>.537$; for $p<.05$, $r>.423$)
GRAND INDEX MASTERS (1985-60 BASE MEAN) VS MIAMI BEACH SEA SURFACE TEMPERATURE

TEMP TIME SERIES		MASTER CHRONOLOGIES					
		MA MID	MA DEEP	MA ALL	DL MID	DL DEEP	DL ALL
3 MO	JAS	-0.145	0.295	0.058	-0.337	0.009	-0.223
	OND	0.325	0.255	0.304	0.289	0.212	0.290
	JFM	0.432	0.421	0.448	0.391	0.375	0.427
	AMJ	-0.077	-0.001	-0.043	-0.132	-0.090	-0.124
	JAS	-0.202	0.218	-0.010	-0.441	-0.152	-0.350
6 MO	JASOND	0.126	0.355	0.238	0.013	0.154	0.077
	ONDJFM	0.414	0.373	0.413	0.371	0.329	0.394
	JFMAMJ	0.297	0.319	0.323	0.249	0.260	0.283
	AMJJAS	-0.140	0.133	-0.015	-0.313	-0.134	-0.259
12	JASONDJFMAM	0.254	0.334	0.303	0.185	0.224	0.224

1980-1960 CORRELATION COEFFICIENTS n=20 (for $p<.01$, $r>.537$; for $p<.05$, $r>.423$)
GRAND INDEX MASTERS (1985-60 BASE MEAN) VS MIAMI BEACH SEA WATER DENSITY

DENSITY TIME SERIES		MASTER CHRONOLOGIES					
		MA MID	MA DEEP	MA ALL	DL MID	DL DEEP	DL ALL
3 MO	JAS	0.328	0.343	0.361	0.144	0.393	0.261
	OND	0.634	0.574	0.645	0.431	0.733	0.598
	JFM	0.618	0.480	0.591	0.457	0.648	0.581
	AMJ	0.560	0.539	0.582	0.496	0.774	0.659
	JAS	0.347	0.479	0.438	0.192	0.487	0.337
6 MO	JASOND	0.556	0.530	0.582	0.335	0.652	0.499
	ONDJFM	0.639	0.542	0.633	0.450	0.706	0.601
	JFMAMJ	0.620	0.546	0.622	0.507	0.764	0.663
	AMJJAS	0.505	0.556	0.562	0.394	0.703	0.562
12	JASONDJFMAM	0.623	0.567	0.636	0.451	0.750	0.619

(Where name of the environmental time series refers to the months which were averaged. For example, JAS is July, August, and September).

FIGURE CAPTIONS

Fig. 1a. Example of star coral Montastrea annularis.

Fig. 1b. Example of brain coral Diploria labyrinthiformis.

Fig. 2. Sketch map of search/collection areas in Broward County, Florida.

Fig. 3a. M. annularis coral sections (0.5 cm thick) produced with masonary saw.

Fig. 3b. Sample of M. annularis coral section and X-radiograph positive.

Fig. 4a. Sample M. annularis coral section and associated X-radiograph positive showing severe bioerosion and poorly defined banding.

Fig. 4b. Skeleton of brain coral D. labyrinthiformis showing large boring clam (Lithophaga nigra) trace through center of skeleton.

Fig. 5. Sample X-radiograph positive of M. annularis showing annual growth banding and measurement transects. X-radiograph is actual size.

Fig. 6. Average growth rate (cm/yr) for the time period 1985-1970 of M. annularis and D.labyrinthiformis corals at each collection site.

Fig. 7a. Hollywood Master Chronologies for each depth and coral species. For each graph the vertical axis is the average index value and the horizontal axis is the year of averaging. The number of corals included in each average is presented at the appropriate year along the upper and lower graph inside borders for the indicated master. Where a number is not shown, it is the same as the number to the left.

Fig. 7b. Ft. Lauderdale Master Chronologies for each depth and coral species.

Fig. 7c. Pompano Master Chronologies for each depth and coral species.

Fig. 7d. Deerfield Master Chronologies for each depth and coral species.

Fig. 8a. Mid depth master chronologies for each site (Hollywood, Ft. Lauderdale, Pompano, Deerfield) and coral species.

Fig. 8b. Deep depth master chronologies for each site (Hollywood, Pompano, Deerfield) and coral species.

Fig. 9a. Grand Master Chronologies of all corals of each species by each depth.

Fig. 9b. Grand Master Chronologies of all corals of each species.

Figs. 10a, 10b. Average monthly sea surface temperature at Miami Beach Tide station and seasonal averages for each year. The designation (PY) indicates data of the previous year was used in the averaging.

Figs. 11a, 11b. Average monthly sea surface density at Miami Beach Tide station and seasonal averages for each year. The designation (PY) indicates data of the previous year was used in the averaging.

1A

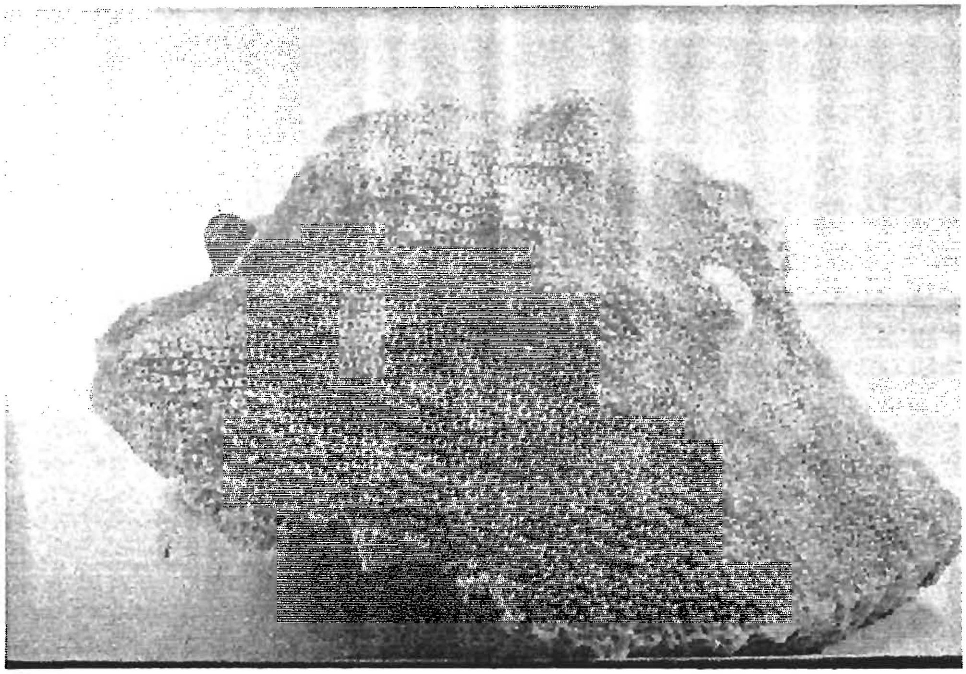


Figure la. Example of star coral *M. annularis*.

1B

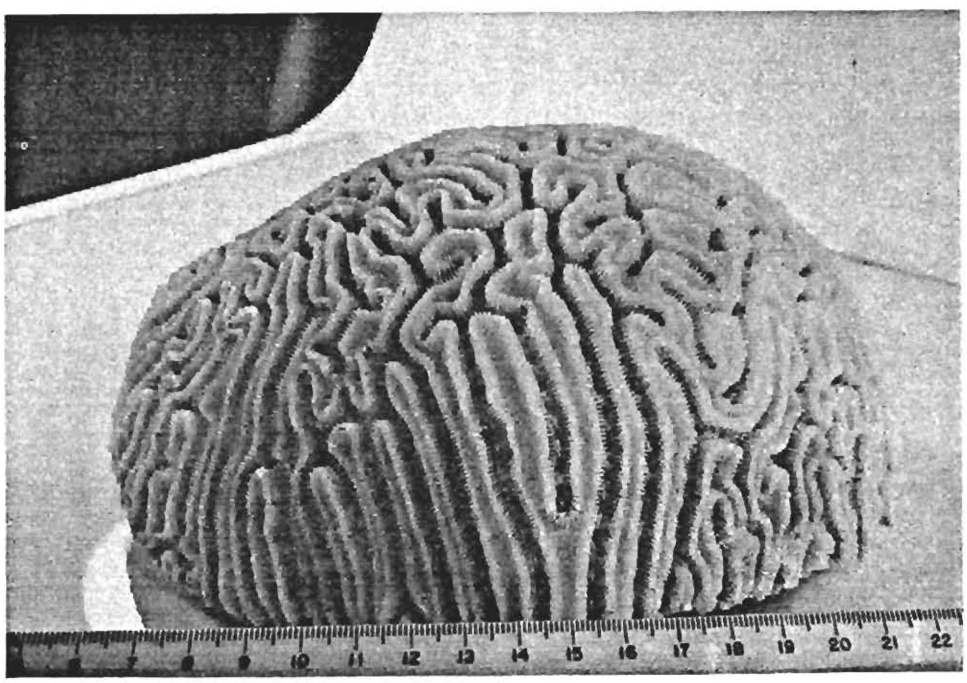


Figure lb. Example of brain coral *D. labyrinthiformis*.

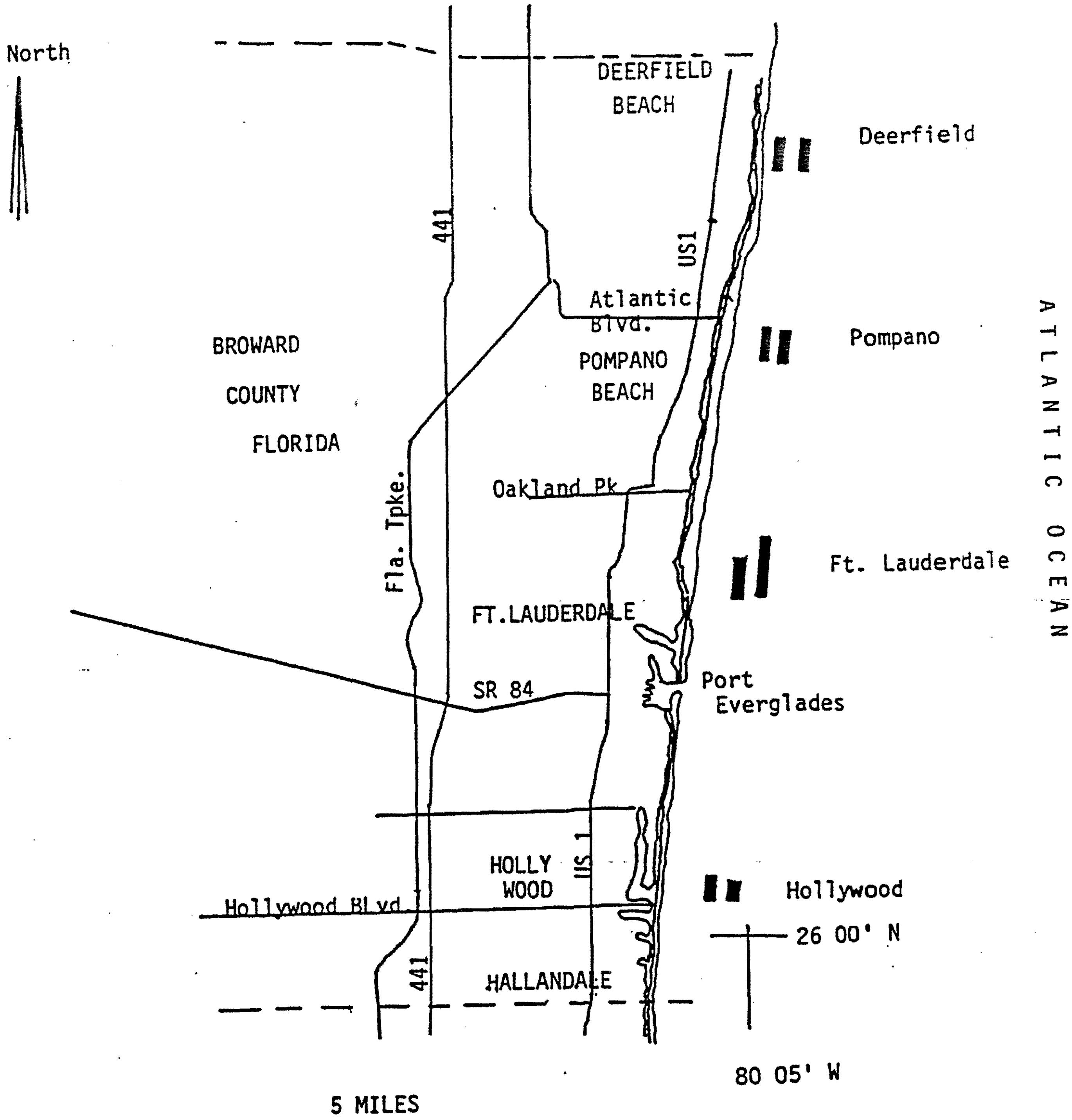


Figure 2. Sketch map of search/collection areas in Broward County, Florida. Rectangles near shore represent Mid (9m) depth reefs. Rectangles off shore represent Deep (18m) depth reefs.

3A

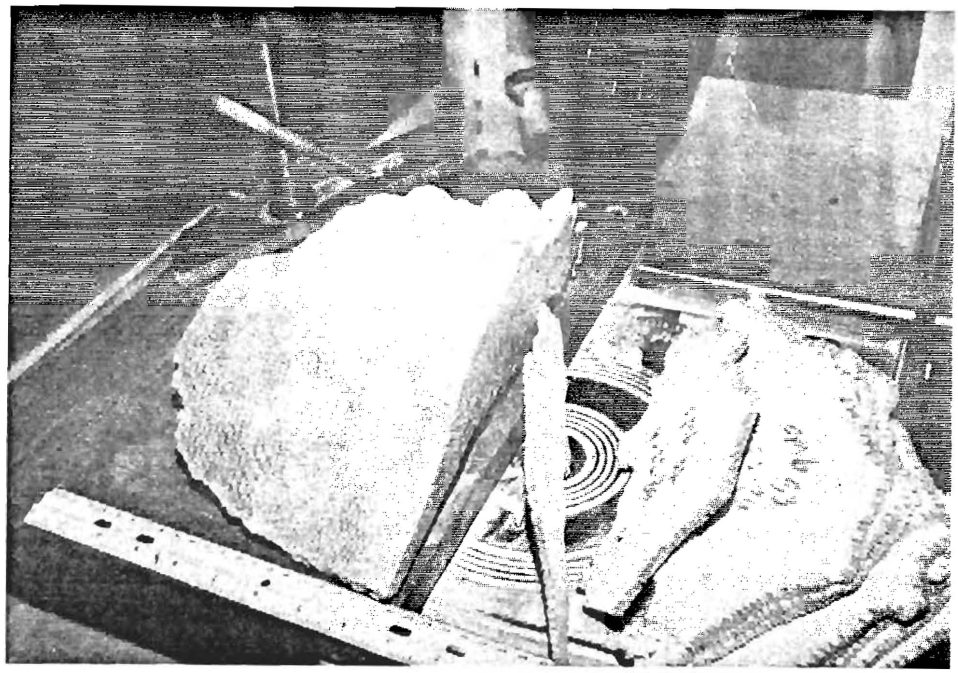


Figure 3a. M. annularis coral sections (0.5 cm thick) produced with masonry saw.

3B

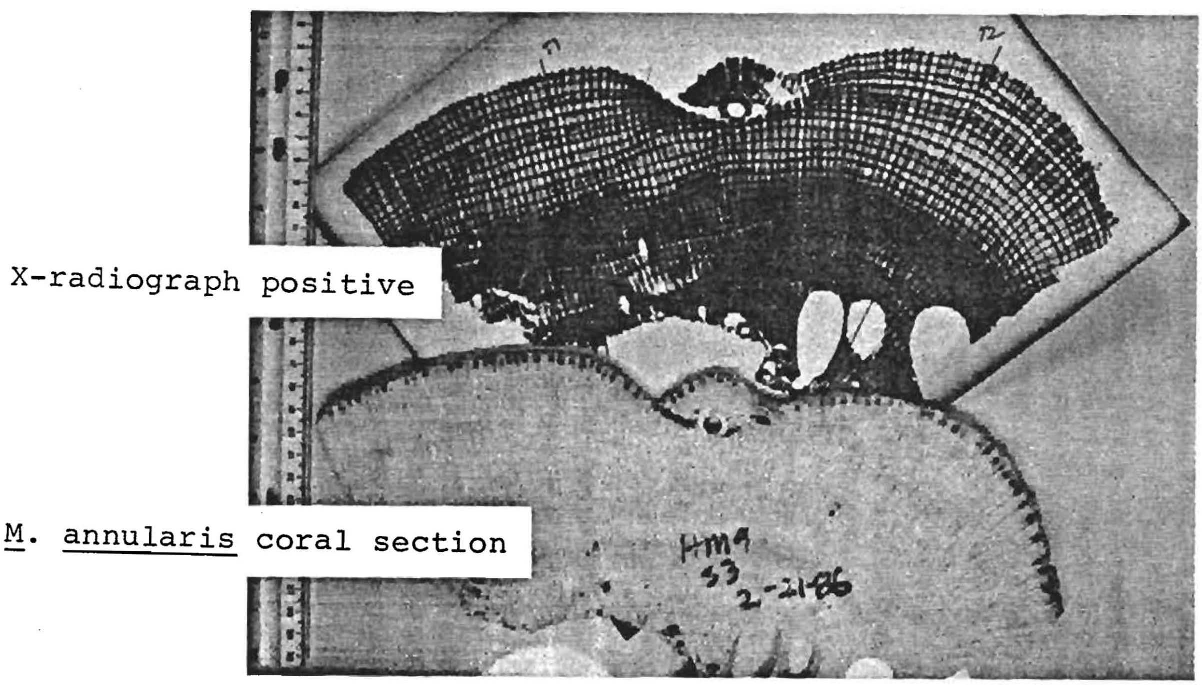


Figure 3b. Sample of M. annularis coral section and X-radiograph positive.

4A

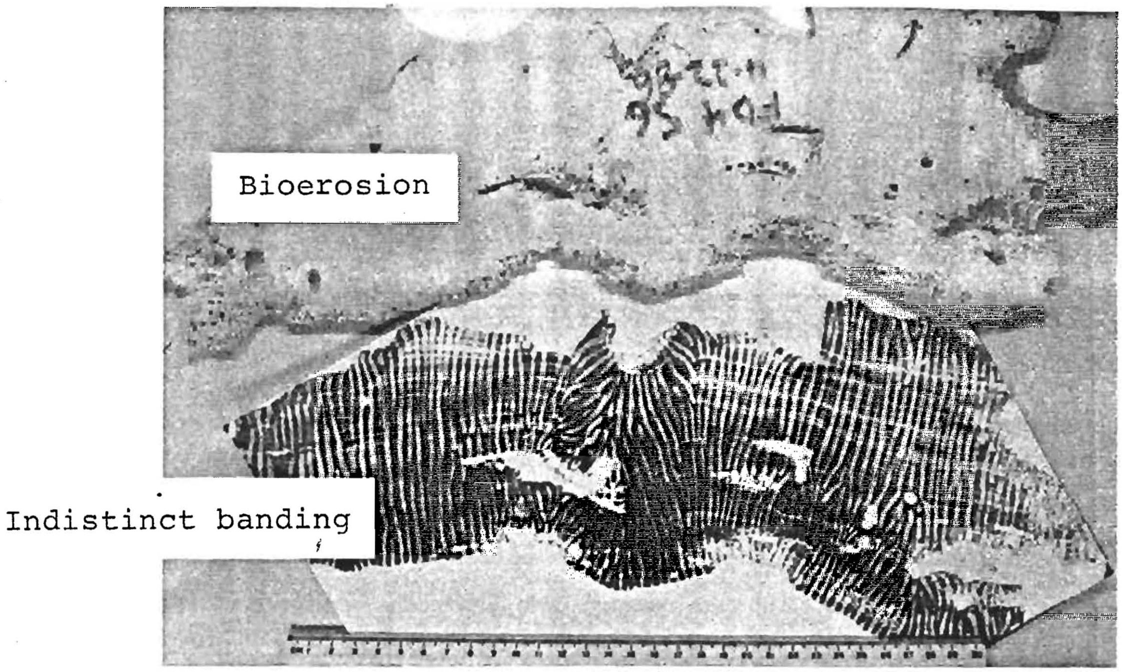


Figure 4a. Sample M. annularis coral section and associated X-radiograph positive showing severe bioerosion and poorly defined banding.

4B

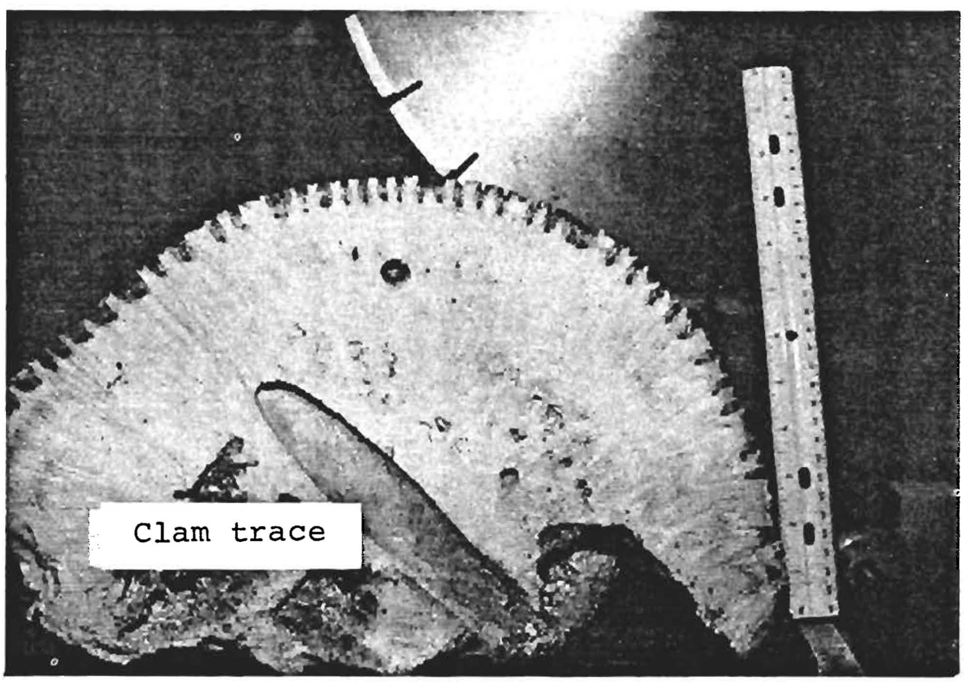


Figure 4b. Skeleton of brain coral D. labyrinthiformis showing large boring clam (Lithophaga nigra) trace through center of skeleton.

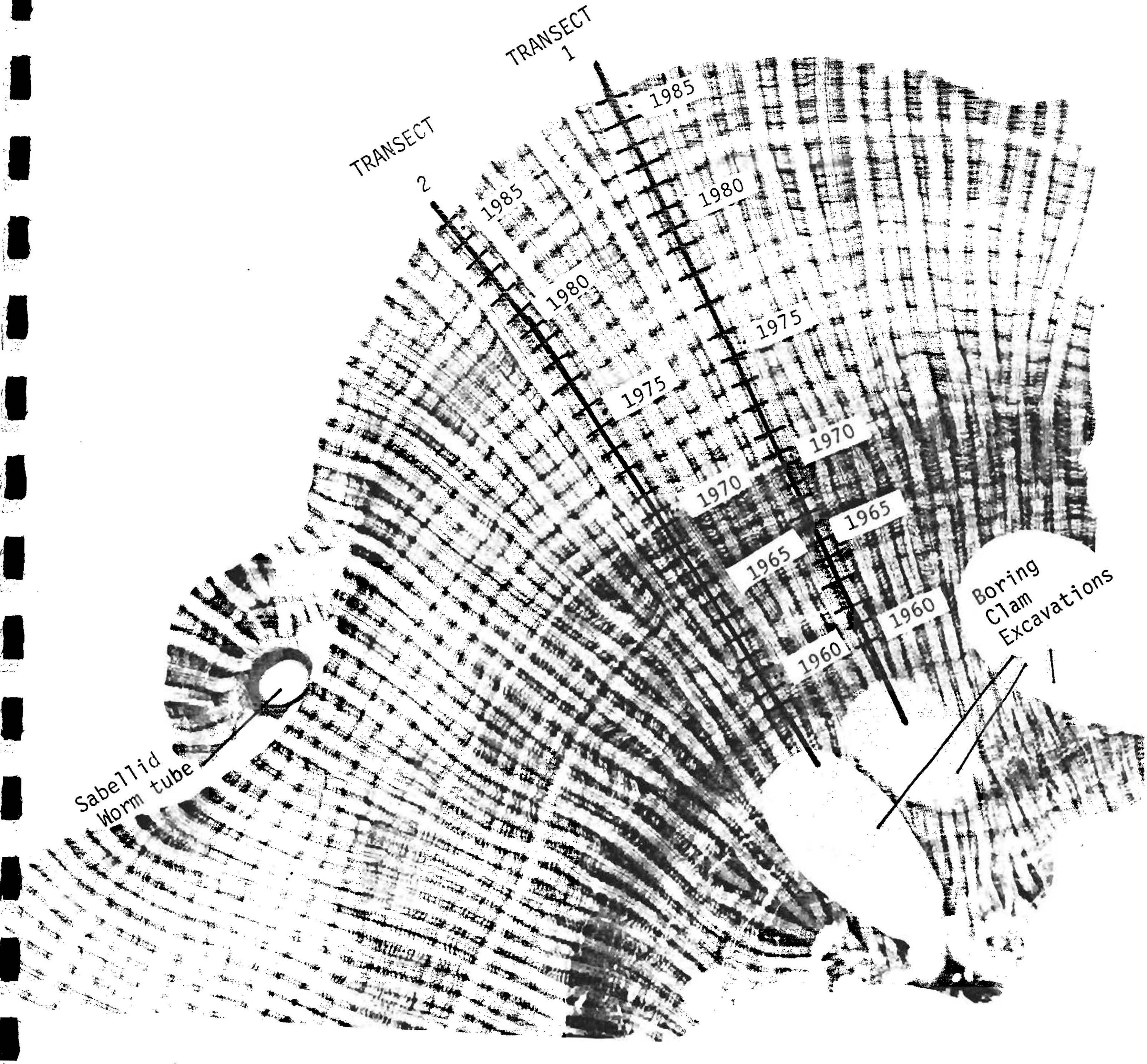
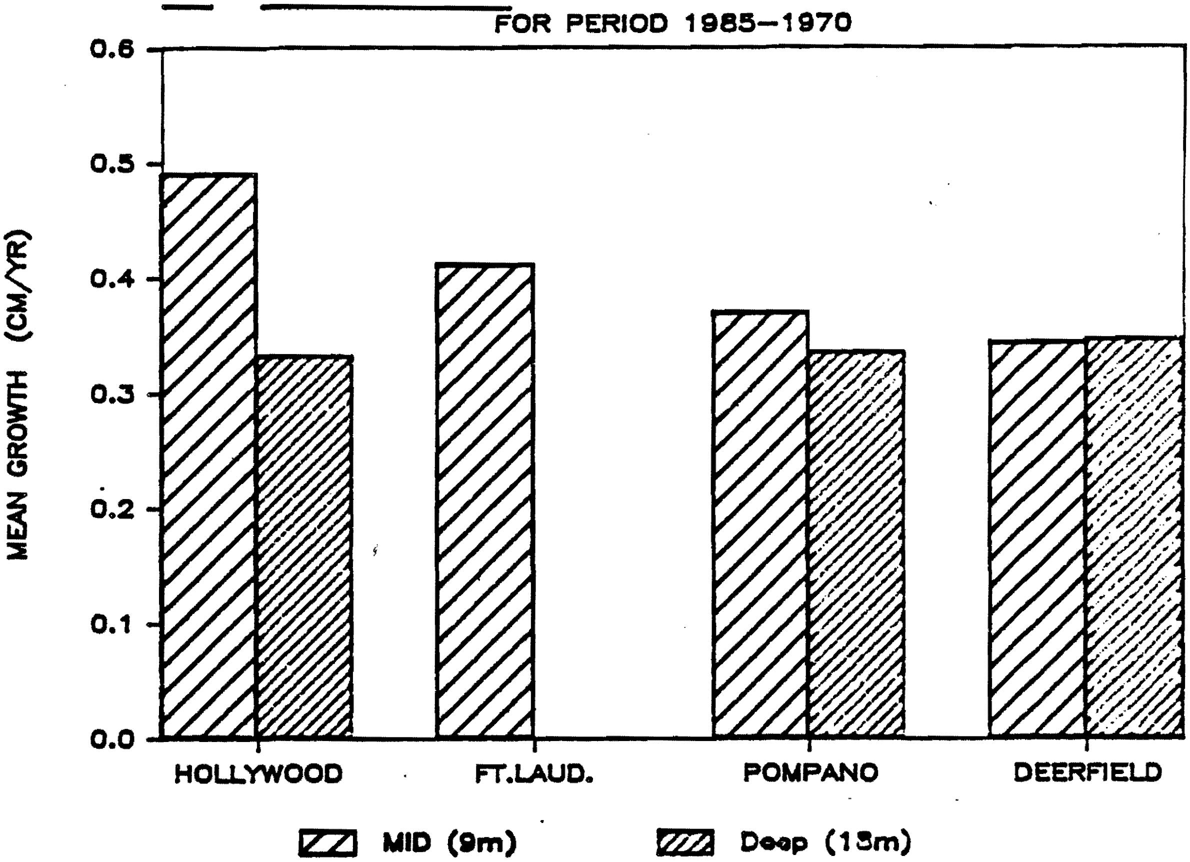
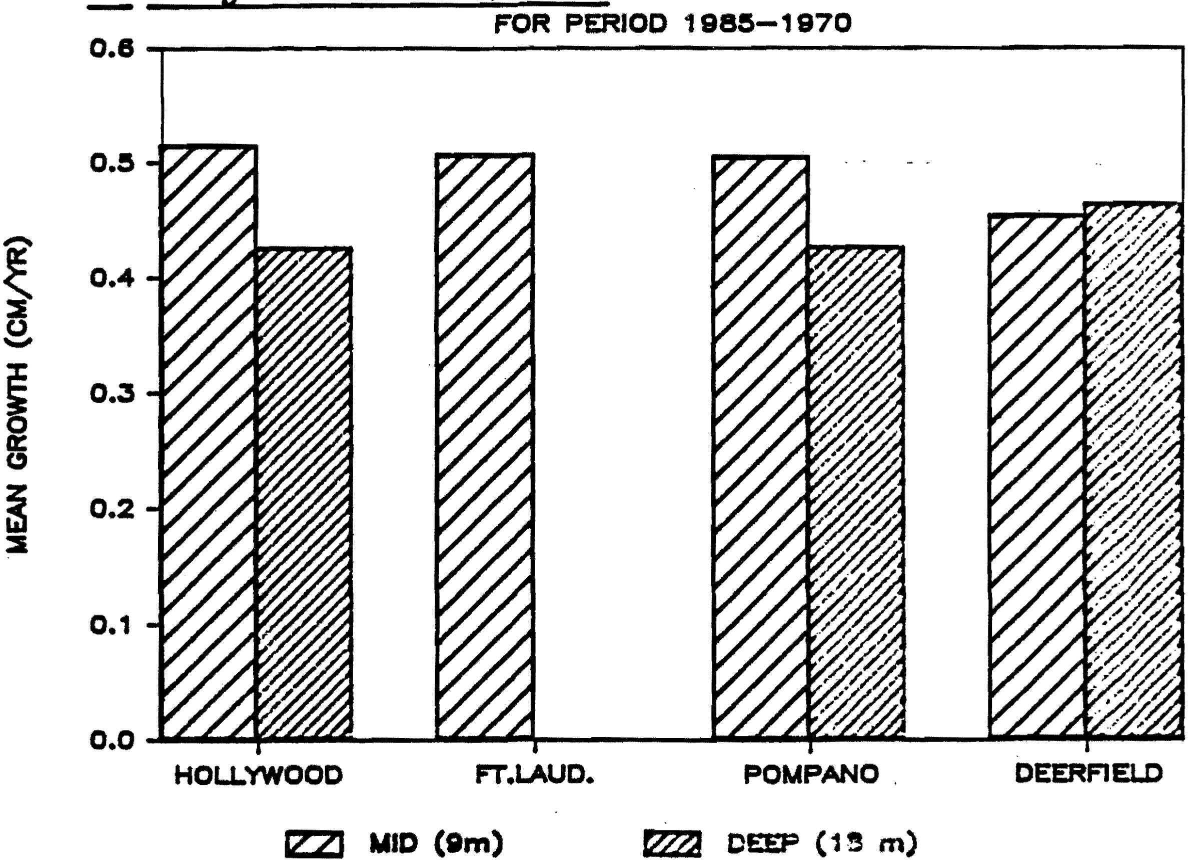


Figure 5. Sample X-radiograph positive showing annual growth banding and measurement transects. X-radiograph is actual size.

M. annularis SITES: GROWTH RATE

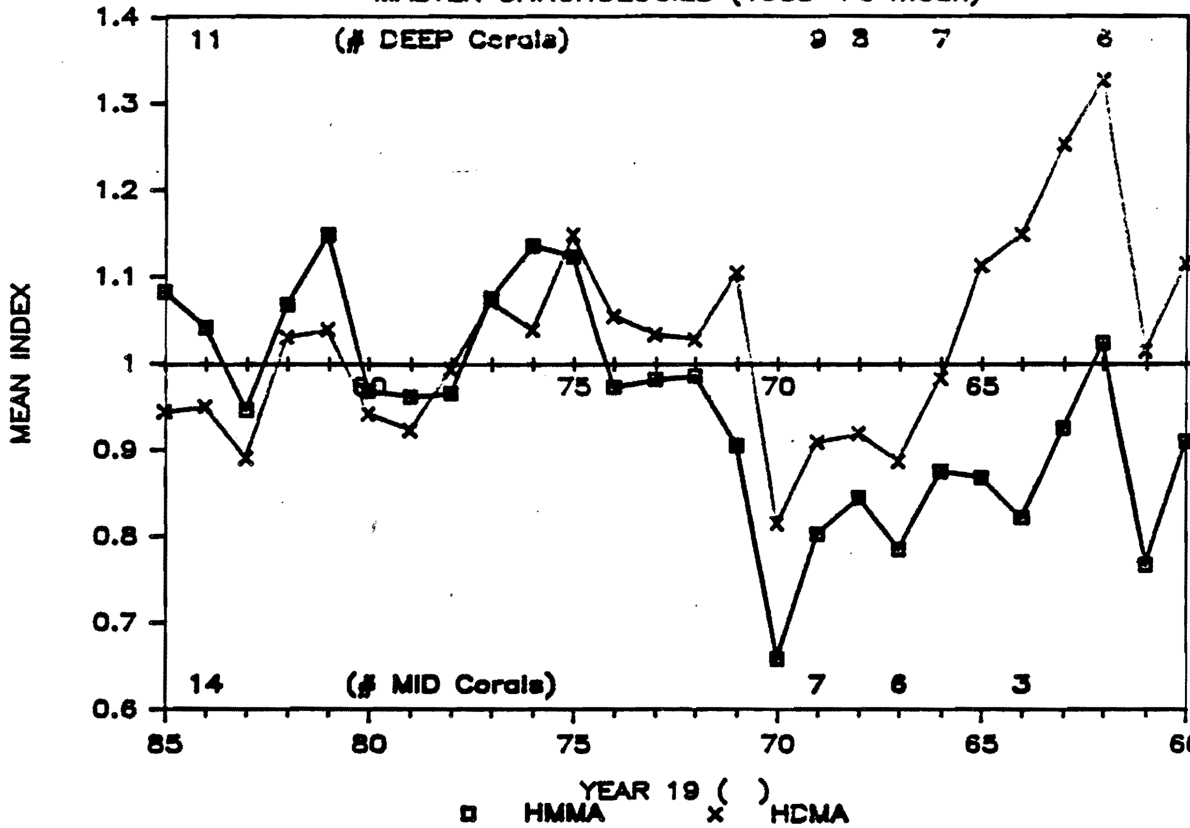


D.labyrinthiformis SITES: GROWTH RATE



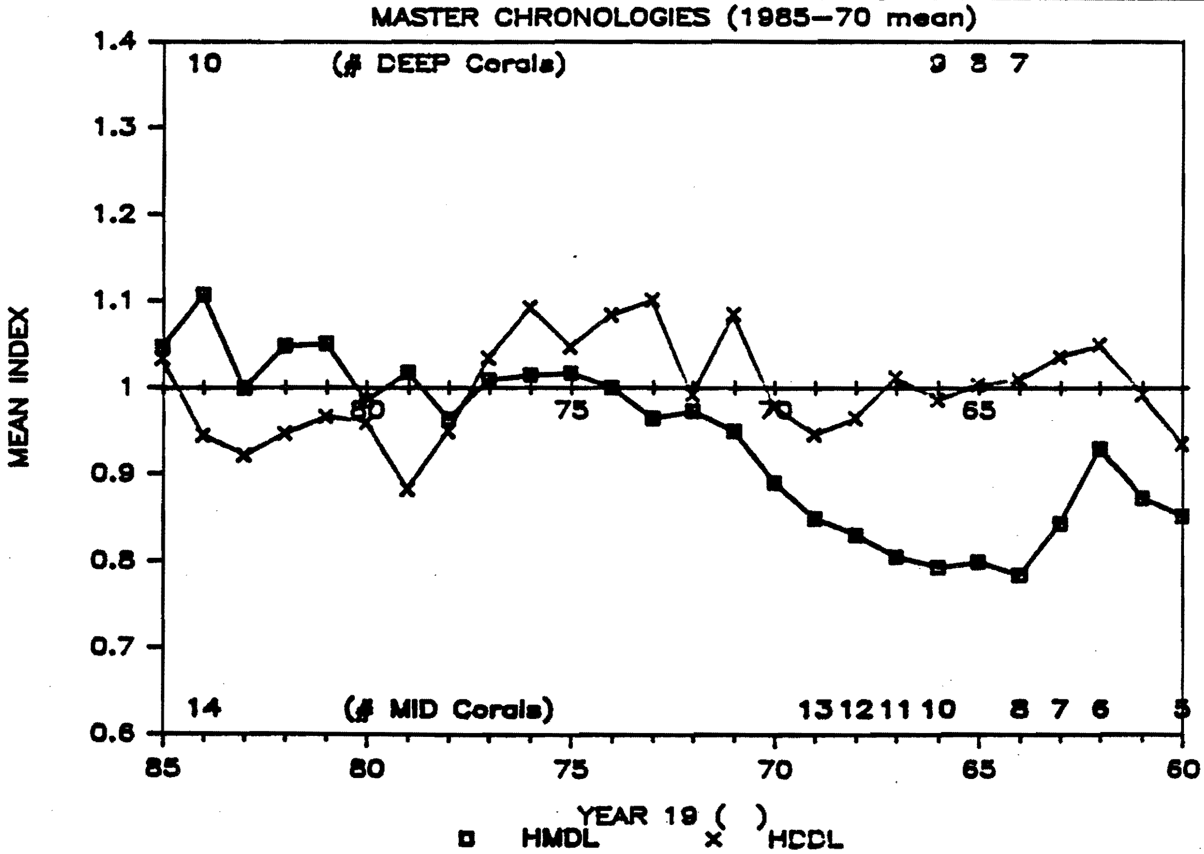
HOLLYWOOD MID,DEEP <u>M</u>. <u>annularis</u>

MASTER CHRONOLOGIES (1985–70 mean)

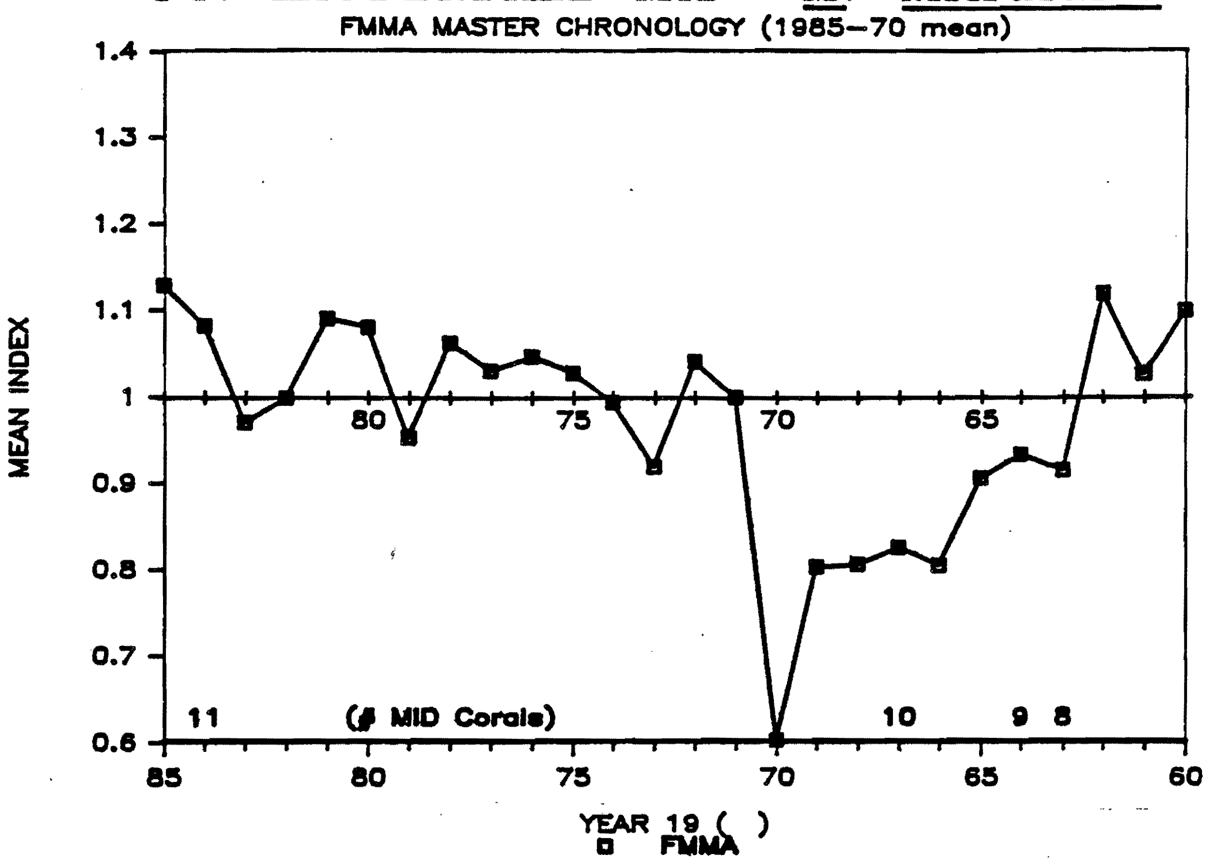


HOLLYWOOD MID,DEEP <u>D.labyrinthiformis</u>

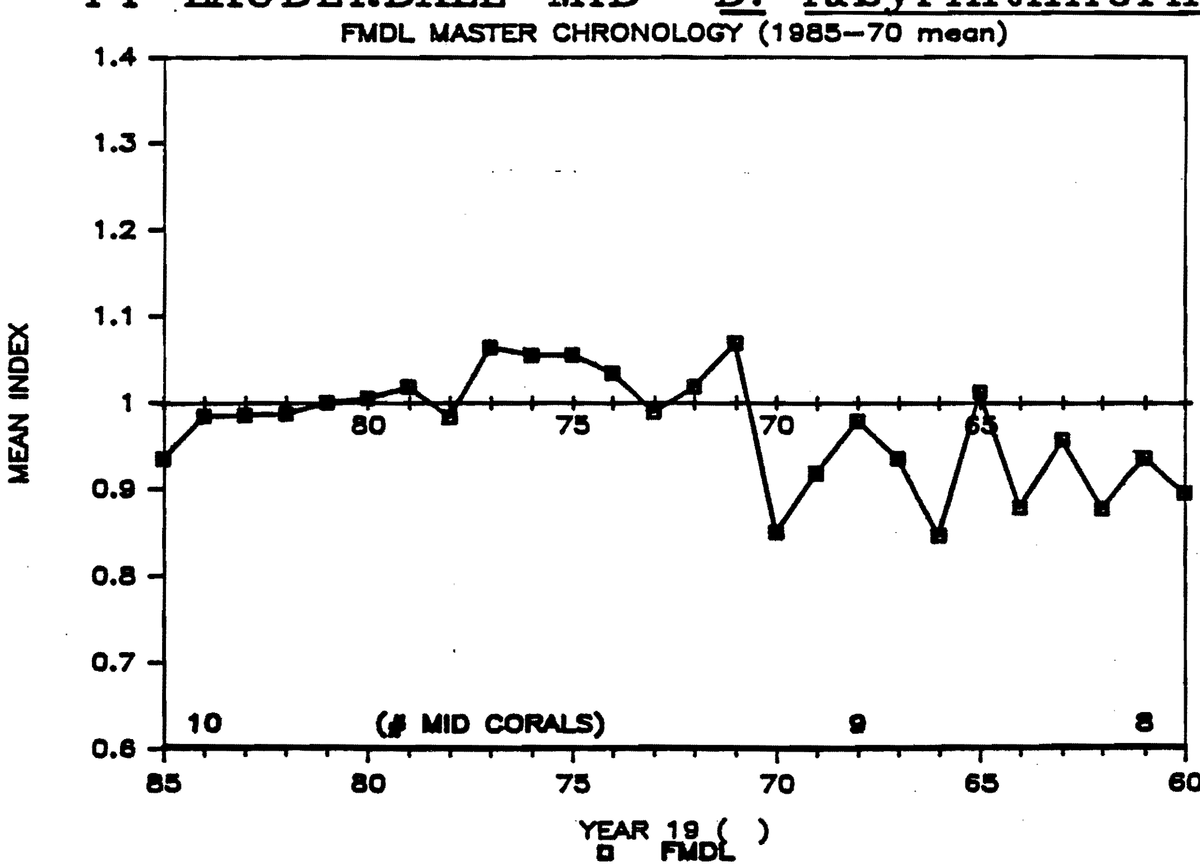
MASTER CHRONOLOGIES (1985–70 mean)



FT. LAUDERDALE MID M. annularis

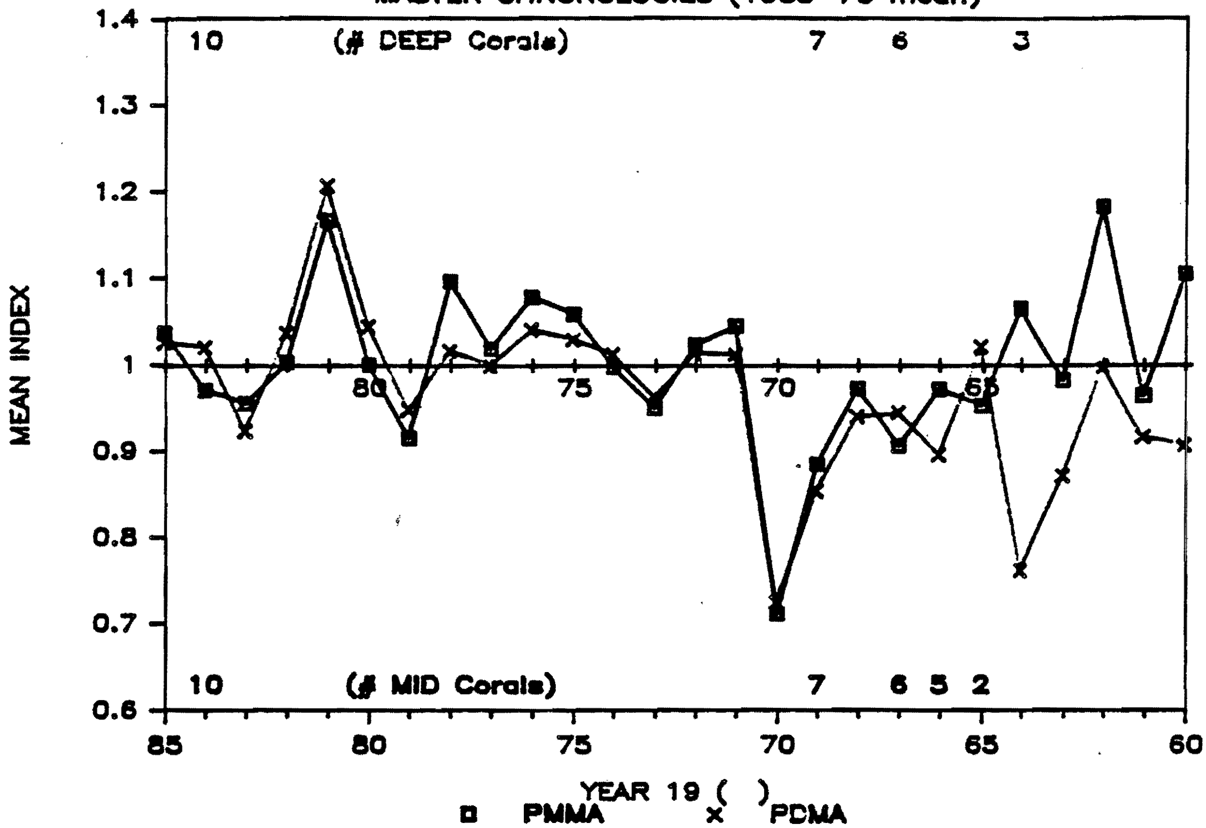


FT LAUDERDALE MID D. labyrinthiformis



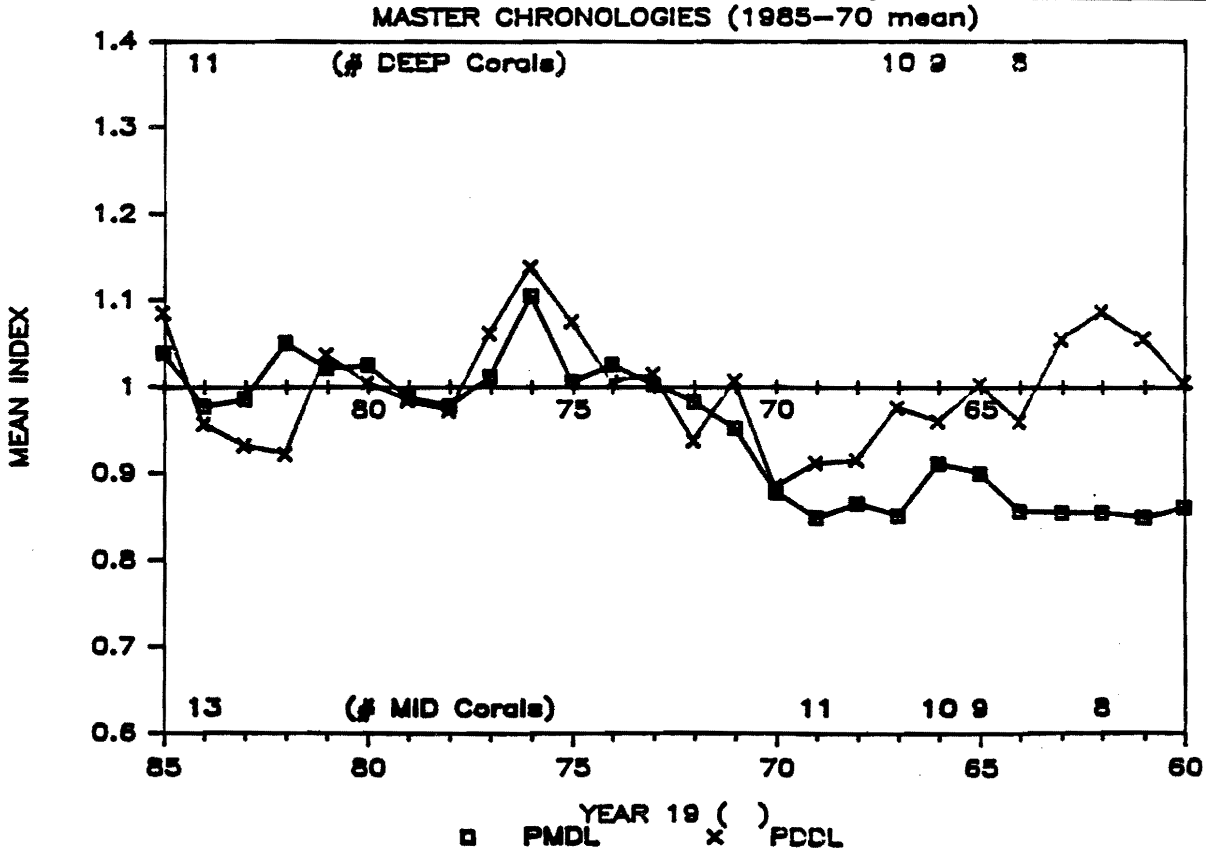
POMPANO MID,DEEP M. annularis

MASTER CHRONOLOGIES (1985–70 mean)



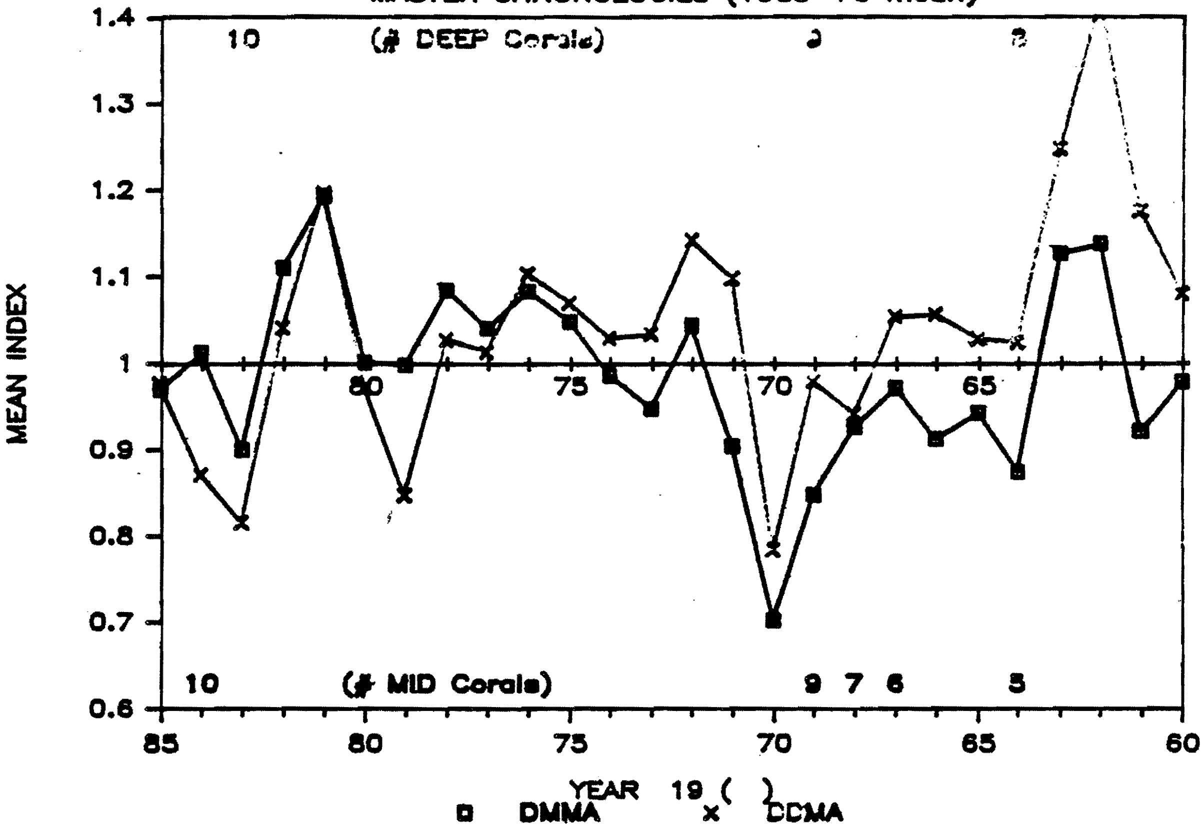
POMPANO MID,DEEP D. labyrinthiformis

MASTER CHRONOLOGIES (1985–70 mean)



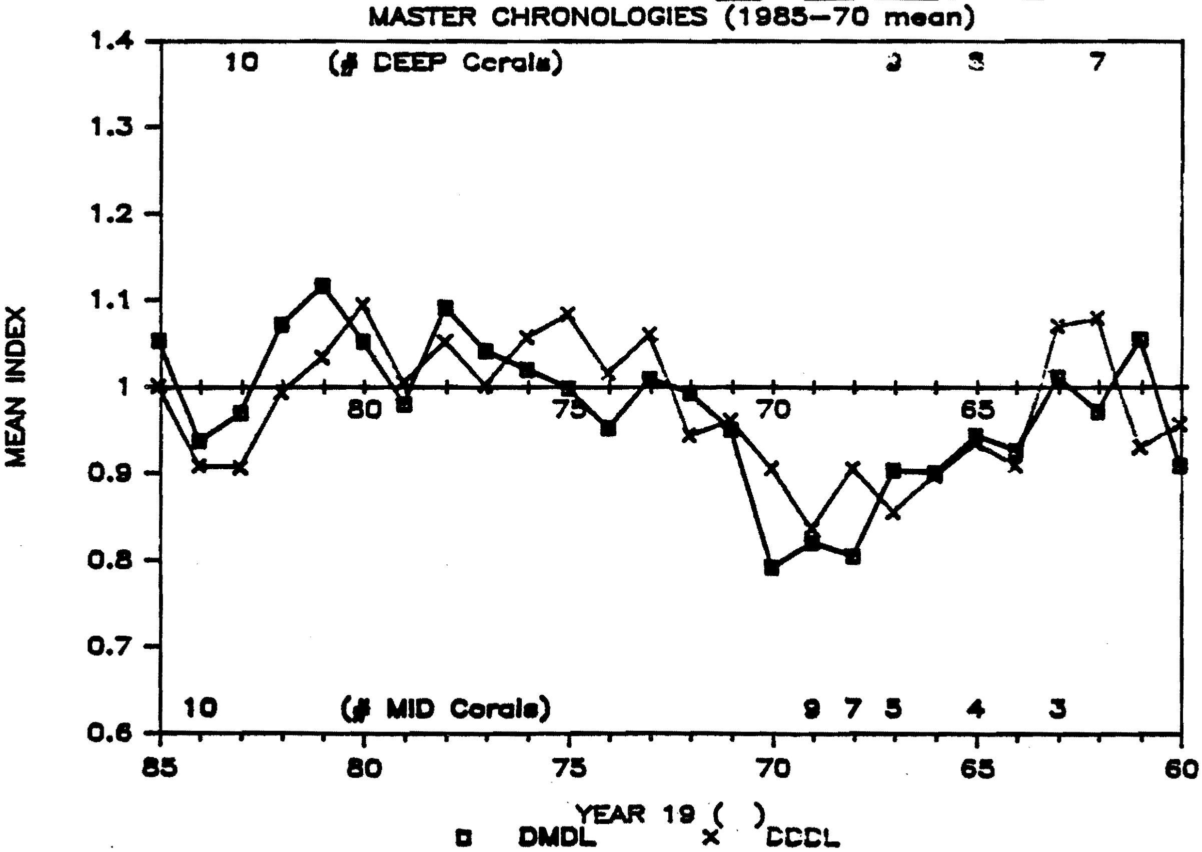
DEERFIELD MID,DEEP M. annularis

MASTER CHRONOLOGIES (1985–70 mean)

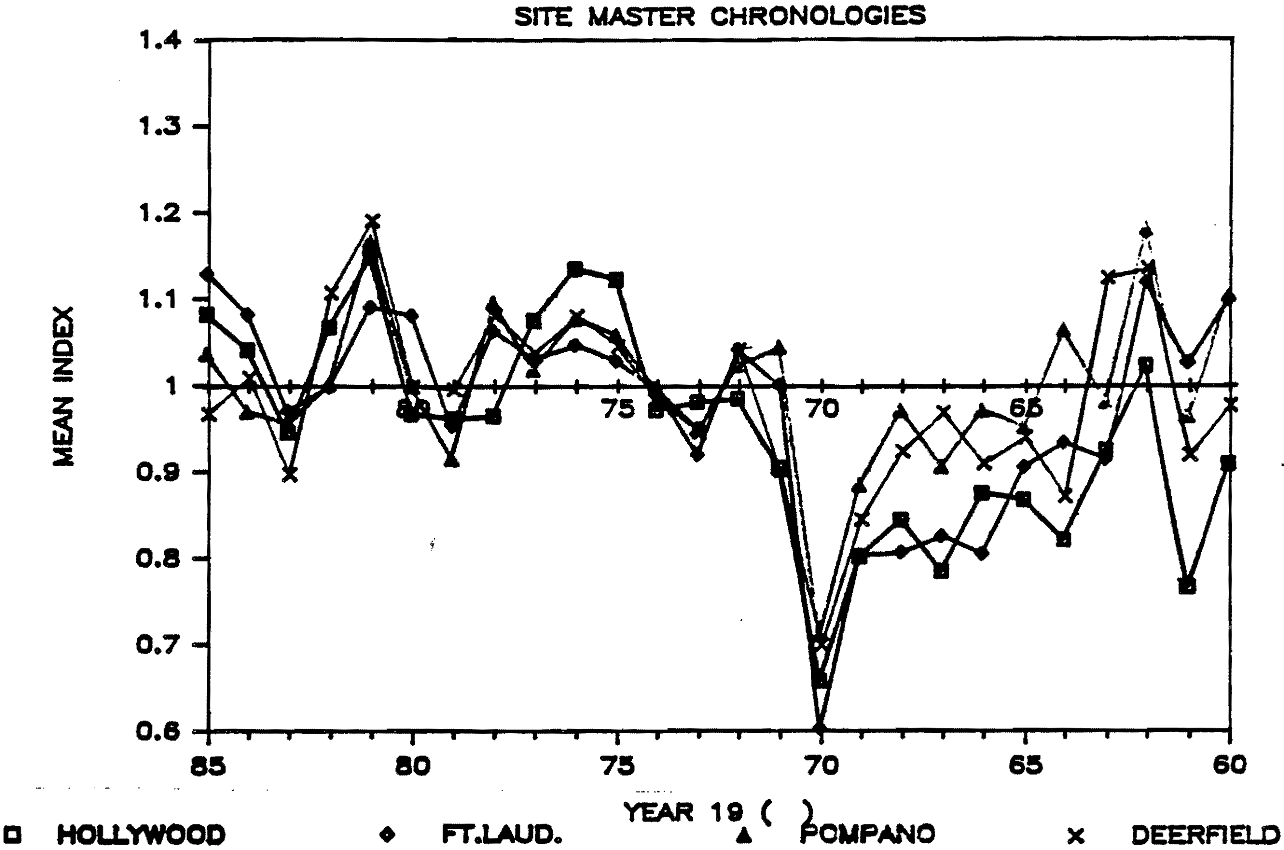


DEERFIELD MID,DEEP D. labyrinthiformis

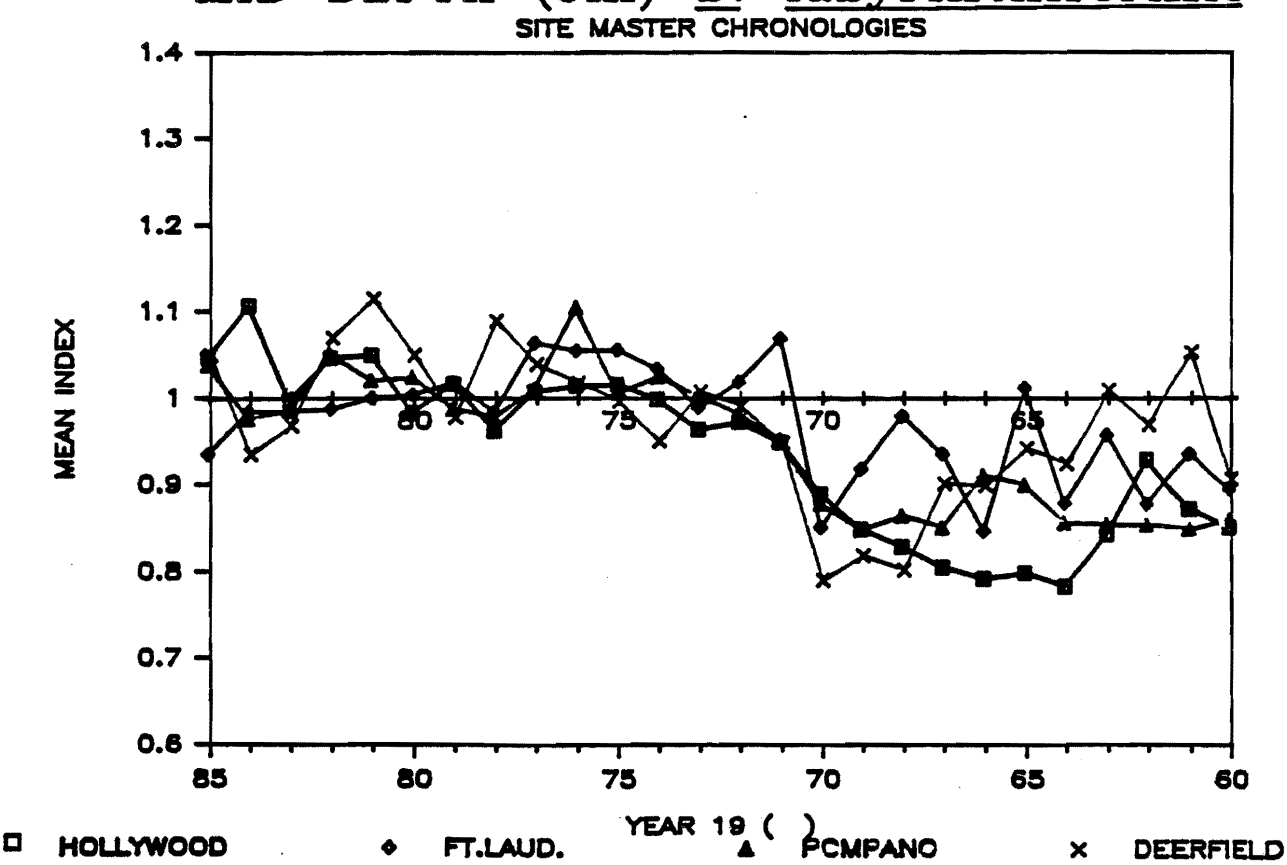
MASTER CHRONOLOGIES (1985–70 mean)



MID DEPTH (9m) M. annularis

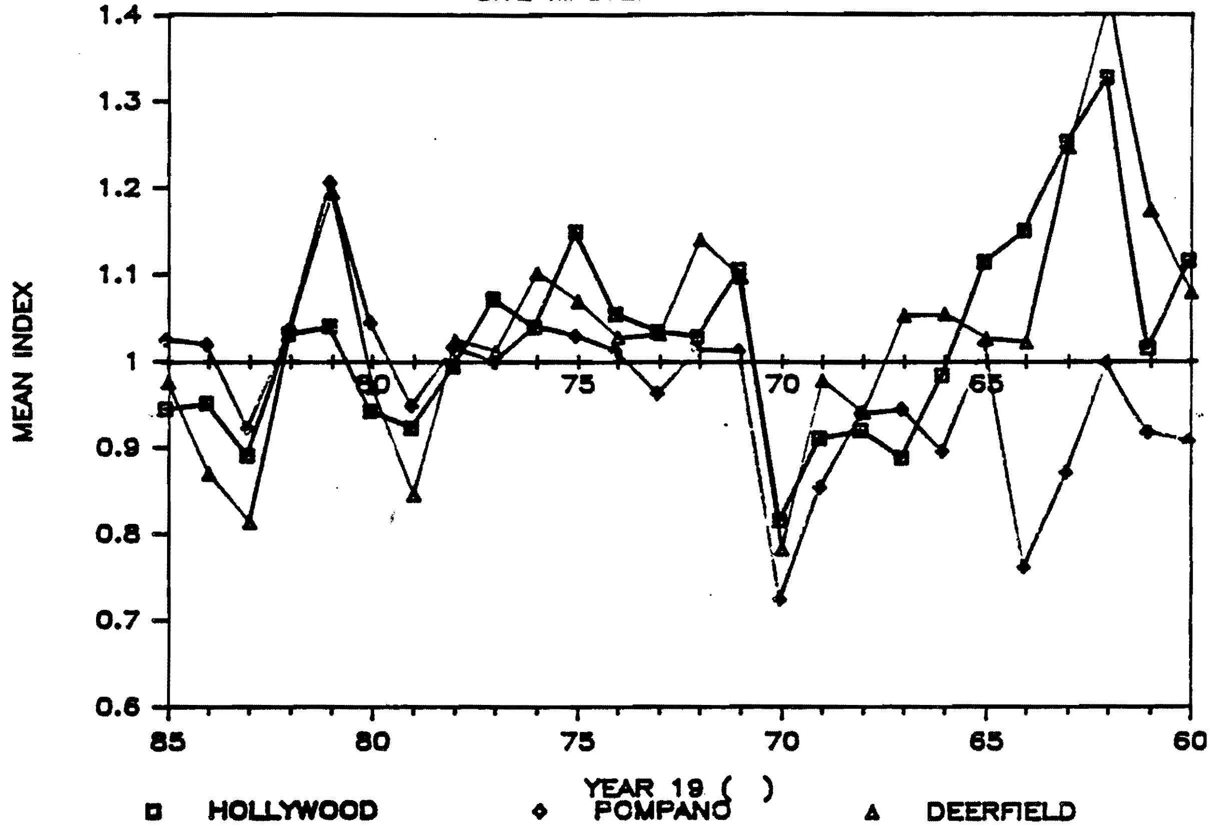


MID DEPTH (9m) D. labyrinthiformis



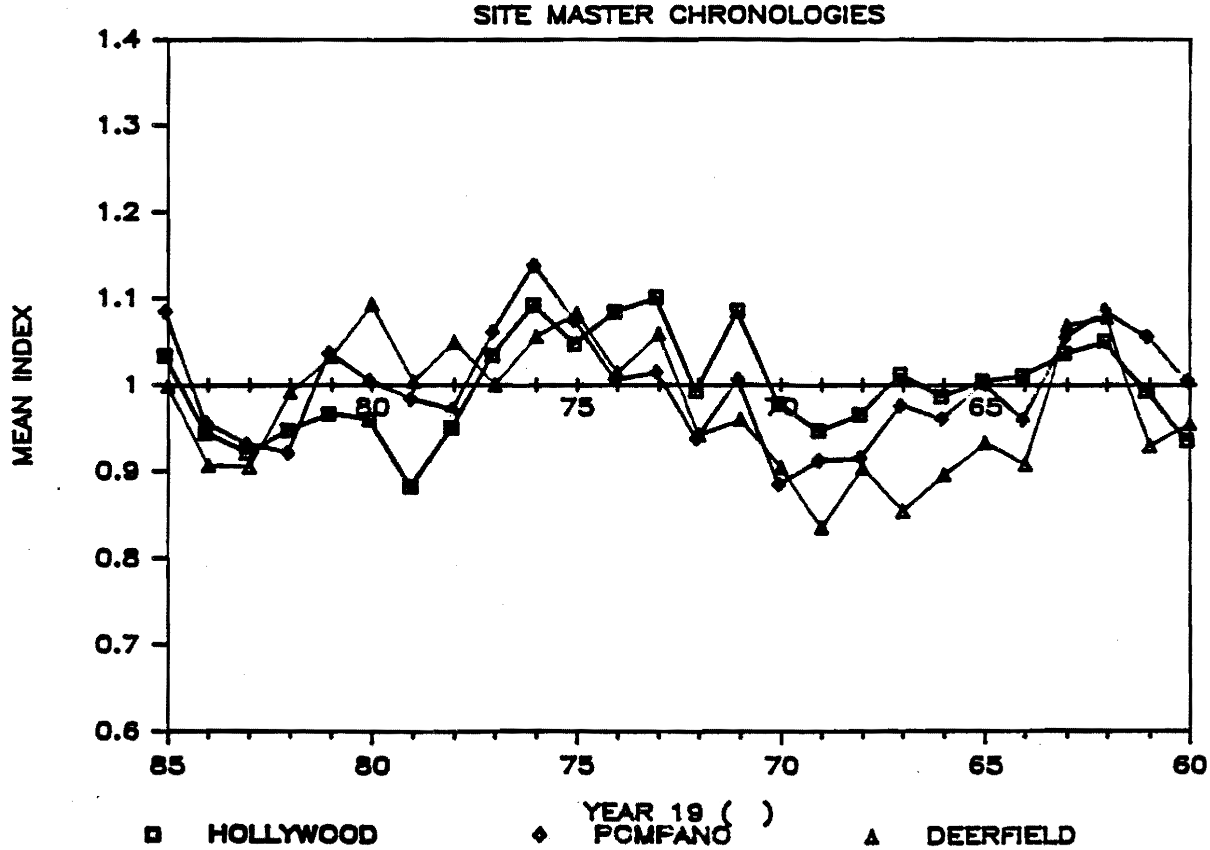
DEEP DEPTH (18m) *M. annularis*

SITE MASTER CHRONOLOGIES

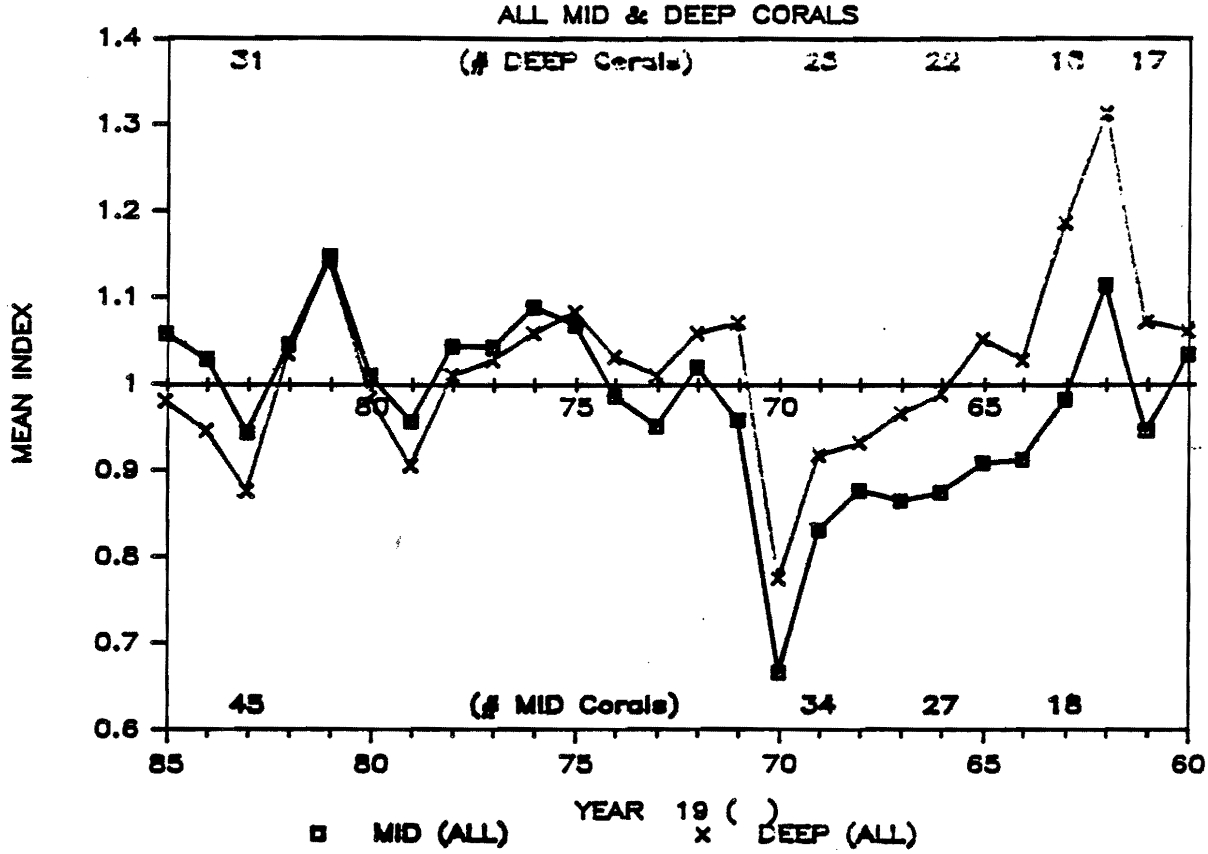


DEEP DEPTH (18m) *D.labyrinthiformis*

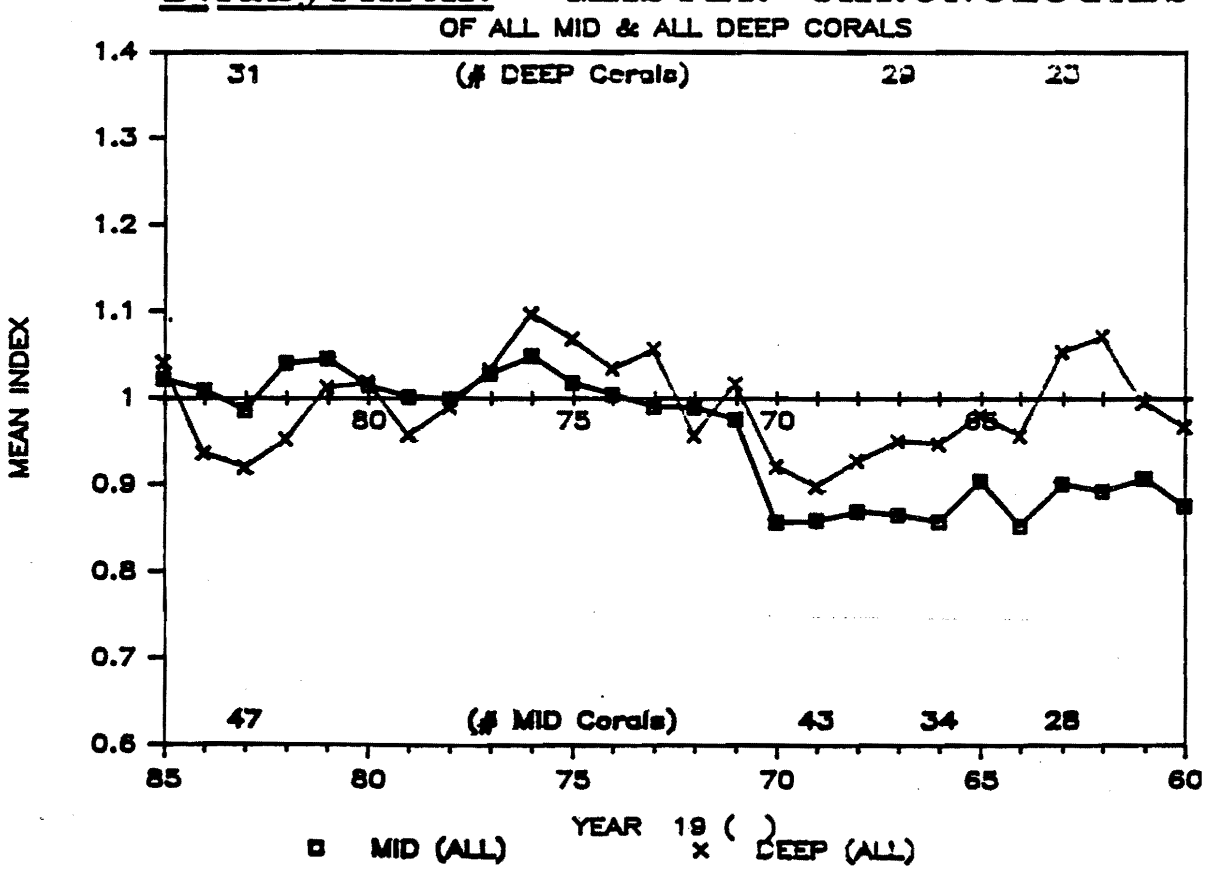
SITE MASTER CHRONOLOGIES



M. annularis MASTER CHRONOLOGIES

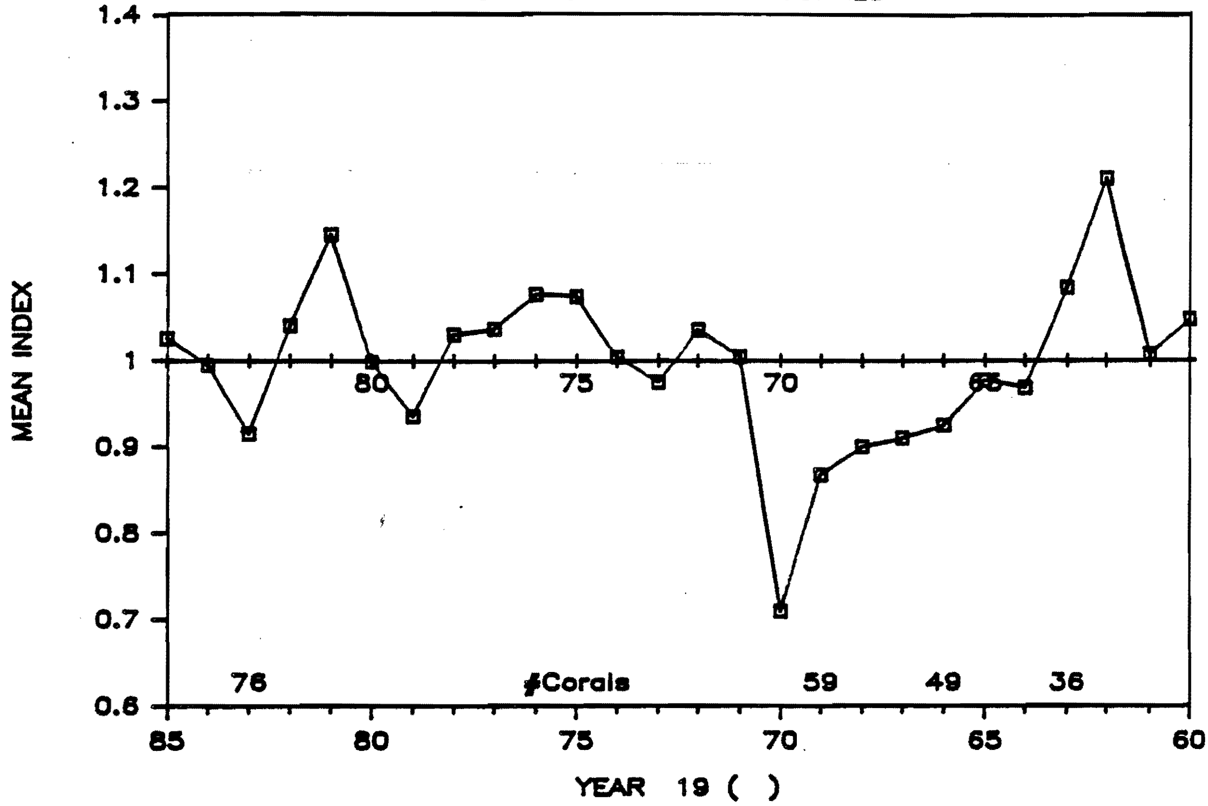


D.labyrinth. MASTER CHRONOLOGIES



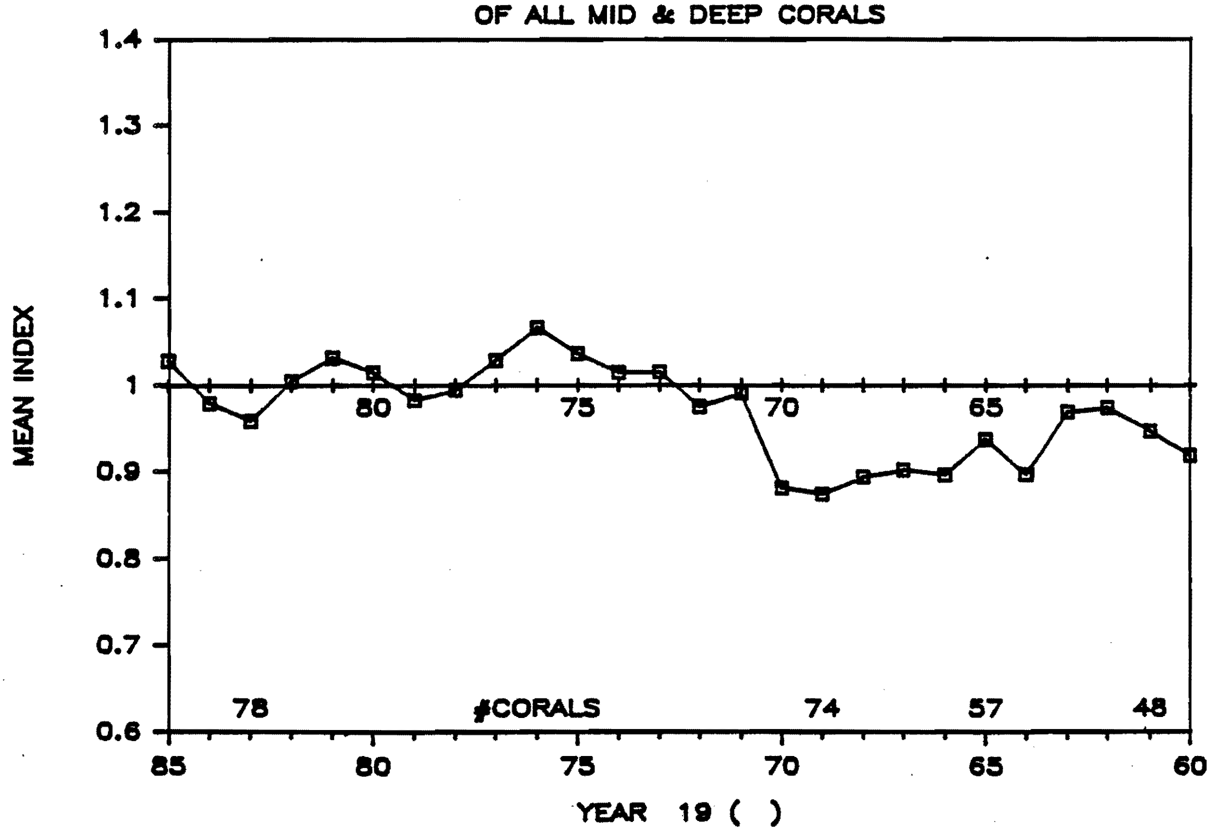
M.ANNULARIS GRAND MASTER CHRONOL.

OF ALL MID & DEEP CORALS



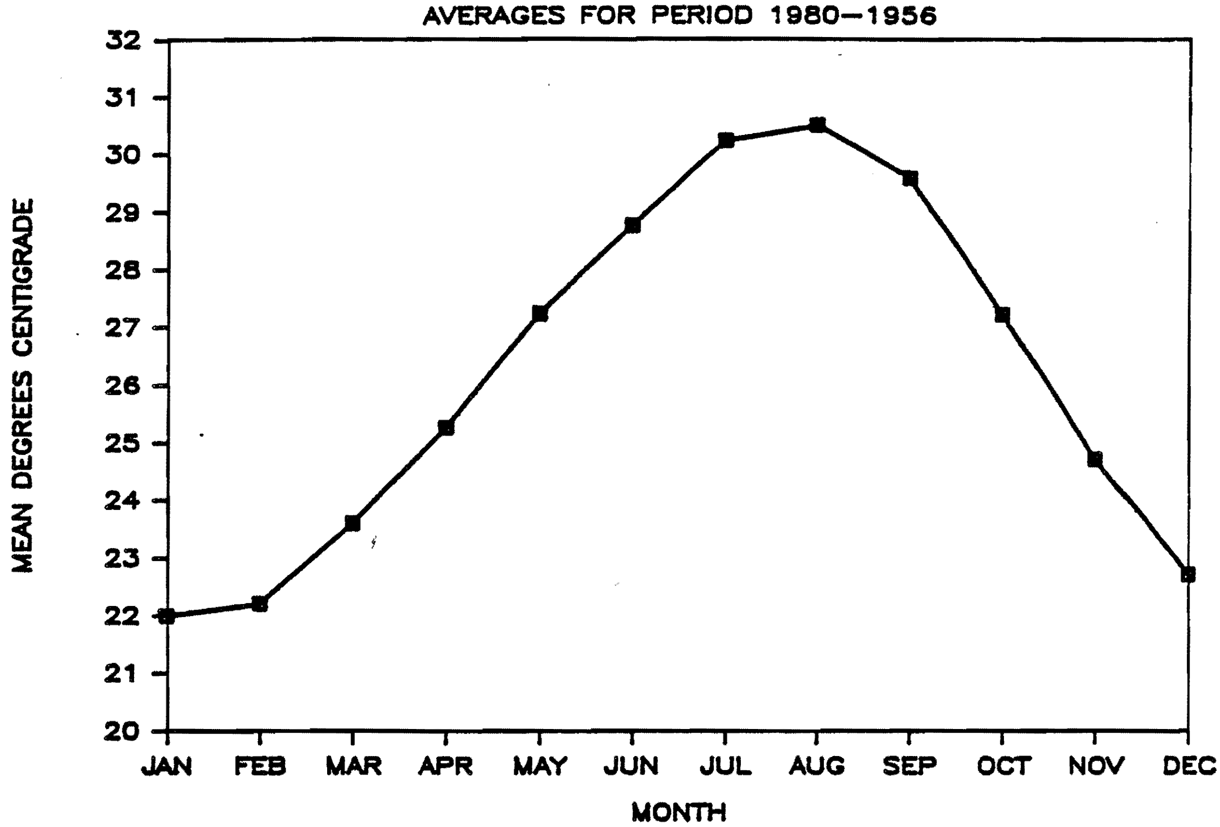
D.LABYRINTH. GRAND MASTER CHRONOL.

OF ALL MID & DEEP CORALS



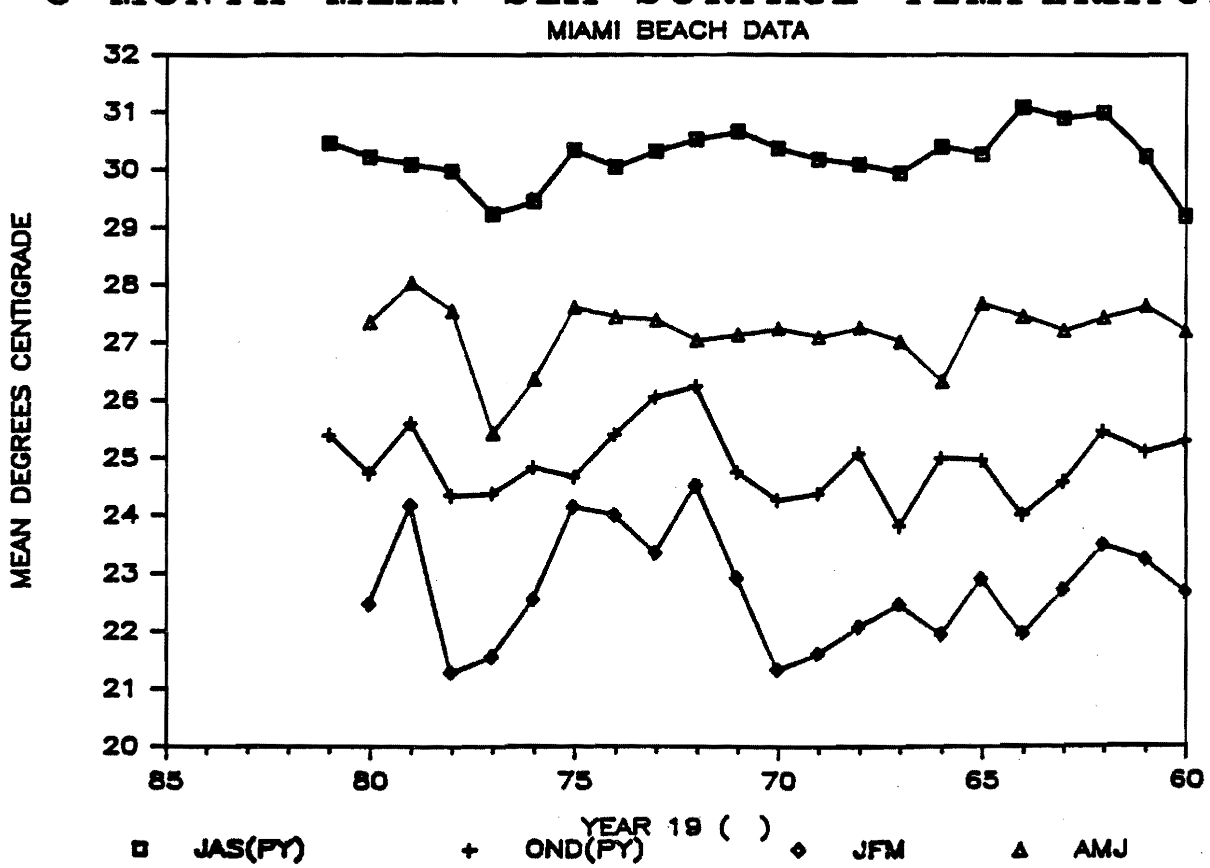
10A

MIAMI BEACH SEA SURFACE TEMPERATURE



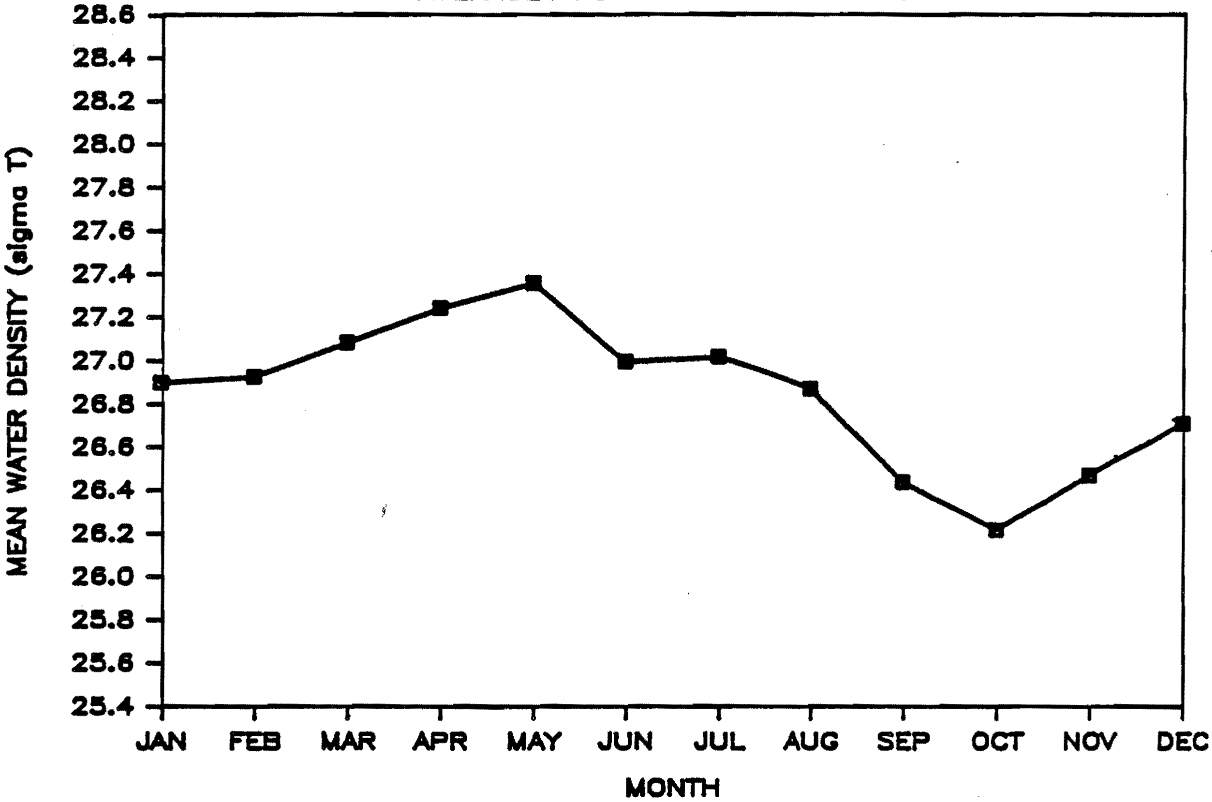
10B

3 MONTH MEAN SEA SURFACE TEMPERATURE



11A

MIAMI BEACH SEAWATER DENSITY



11B

3 MONTH MEAN SEA WATER DENSITY